U.S. SHALE-OIL HUBBERT PRODUCTION PEAK: CIVILIZATION'S ULTIMATE ENERGY FORECAST

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A geologist, M. King Hubbert, came up with a logistics trend to explain his observation that oil and mineral exploration and production for a region followed a certain pattern of first increasing production, then a peak in production followed by a decline in production. Critics claimed that the postulated Hubbert trend did not statistically work. However, rather like how free markets work in principle but often fail in reality due to institutional effects (like a failed regulation), externalities (like pollution), and market power problems (like a monopoly), so likewise Hubbert's original trend could be affected by outside influences that simply needed to be conceptualized. And since Hubbert was a geologist, rather than an economist, it took some time for the two disciplines, geology and economics, to actually talk to each other and indeed to interchange among themselves in order to postulate an overarching theory. This treatise, then, is the result of that interchange and explains the economic theory and antithetical influences of the Hubbert Curve. It is about U.S. shale-oil production trends in particular, and other Hubbert related theories in general, and was accepted to be given as an academic presentation at the 43rd International Association for Energy Economics, (IAEE)'s annual International Energy Conference that was to take place in Paris, France, at the Palais des Congrès, on 21 – 24 June 2020, which has been cancelled due to COVID-19 and Corona-Virus concerns. The presentation was to pertain to important potential petroleum supply side production changes in the U.S. and therefore for the World's oil market.

CLASSIFICATION: Q410 Energy: Demand and Supply; D02 Institutions; Q47 Energy Forecasting; Q43 Energy and the Macro Economy

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I. Overview

This treatise is an addendum to Reynolds' (2011). It looks at the U.S. shale-oil production trend, and specifically at the Hubbert peak of that trend. Simmons (2005), Deffeyes (2001), Hubbert, (1962), Norgaard (1990) and Campbell (1997), among others show how there can be a peak in oil production. Reynolds (2002, 2009) explains the economic and cost theory for how and why the Hubbert Curve works, including how the information and depletion effects create such a curve. Nevertheless, Maugeri (2007), Adelman and Lynch (1997), and Lynch (2002) suggest that one should never curve fit an oil production trend, contrary to most economic disciplines where curve fitting using econometrics is the norm. Although, as of early 2020 the COVID-19 recession is greatly affecting petroleum markets. Nevertheless, the Hubbert supply trend is relevant. Also, Reynolds and Umekwe (2019) show that shale-gas and shale-oil can be compliments or substitutes in production. Based on that relationship, once the U.S. shale-oil peak occurs, it may be the world's ultimate Hubbert peak with much smaller and lower Hubbert cycles thereafter. Worldwide petroleum institutions and strategies will also change. This treatise estimates a U.S. shale-oil Hubbert peak, scrutinizes the Hubbert related theories and explores oil price forecasts, taking into account medium run COVID-19 oil demand effects.

OUTLINE:

1. INTRODUCTION

The U.S. shale-oil (also called tight oil and not to be confused with "oil shale") production phenomenon is one of the most important energy resource developments over the last 100 plus years rivalling such episodes as the invention of the assembly line to make cheap internal combustion engine (ICE) cars, the discovery of the great Ghawar oil field in Saudi Arabia and the formation of OPEC in its importance. While many now consider shale-oil as a conventional source of petroleum liquids, it is actually in a geologically separate section of underground rock formations, typically in formations one or two magnitudes older than where conventional oil resources reside in their underground anti-clines. Plus shale-oil requires a completely different set of technologies for extraction compared to conventional oil production, such as horizontal drilling, fracking and proppants, that was not always needed with the large anti-cline enclosed reservoirs of conventional oil. Nevertheless, the U.S. shale-oil phenomenon has helped to steady oil markets over the last 10 years so that oil prices have been reduced roughly 50% from the mid-2000s to mid-2010s average oil price, not to mention a factor, along with the COVID-19 induced demand destruction, in the February-March 2020 oil price decline shock. The relatively cheaper shale-oil has generally helped the world's economy, global warming issues notwithstanding. Even carbon emission reducing advocates, though, can revel in the fact that shale-oil development has increased the supply of shale-natural gas which has helped reduce coal's use and that shale development has lowered oil prices which in turn has helped economic growth in general which in turn has been used to sustain research and development into alternatives-to-carbon energy technologies. In particular, economic growth has helped fund battery technology, which is still a long way off from being able to create a growth sustaining, carbon emission reducing world economy. Indeed, the lack of progress with renewable technology gives all the more reason that the world needs petroleum in general and U.S. shale-oil in particular.

It must be pointed out, though, that as of early 2020, the world is in the midst of a COVID-19 pandemic that is greatly affecting the world's economy and in particular the demand for petroleum and energy. The COVID-19 demand side shock is and will be affecting much of the petroleum industry in ways that may be unforeseen by anyone.

Nevertheless, to completely understand how petroleum markets will unfold going forward both aspects of the oil market, including the COVID-19 demand side shock and the Hubbert supply side trends, as well as petroleum country institutional changes, all need to be touched on to understand the likely interactions that they will have on each other. Therefore, a complete explanation of the Hubbert Curve theory is needed to understand what kind of oil supply limit there likely will be. That is to understand the whole future energy picture, we must divide and conquer the subject in order to understand the separate pieces of the puzzle. To only concentrate on the short run COVID-19 aspects of the energy market will not be helpful in understanding a post-COVID-19 world order without a similarly detailed explanation of petroleum supply side issues, and indeed of the power of petroleum as an energy resource in general.

This treatise, then, in the grand tradition of Hubbert's (1962) momentous report, looks at the trends in U.S. shale-oil production by using a Hubbert Curve technique. Typically, geologists use drilling information with four types of geophysical forecasting methods to try to understand future supplies of petroleum as explained in Brandt (2010), Walls (1992 and 1994) and most crucially in Hubbert (1956 and 1962). These techniques are: 1.) geological density projection, 2.) field size distribution, 3.) discovery process, and 4.) "curve fitting" or what is more appropriately called the Hubbert Curve. The problem with a lot of these techniques is that the shale-oil discovery and production happens so quickly, one after the other, that there really is not enough time to build up enough knowledge to be able to use the first three techniques before what is discovered is well on its way to being drained. Even the Hubbert trend can only be used for understanding the production side trend of extraction rather than the discovery side trend since the two are so close together in timing.

In this treatise, then, we will first go over the theory of why the Hubbert Curve works, including how the concept of an exploration season helps explain a Hubbert Curve theory. Based on the concept of seasonal exploration plans, something called the information and depletion effects can be understood. These effects are shown to determine how the subjective probability of discovery determines the marginal cost of discovery within a season and, based on economic rational expectations, determines marginal cost changes from year to year. The year to year seasonal exploration changes are then mapped into general market changes and then into the trend of production which is how a Hubbert Curve progression is created over time. This can be used to create what is called a Quadratic and a Lambda Hubbert Curve trend. Once the theory of the Hubbert Curve is well established, we can use it, along with typical U.S. economic characteristics, to determine a best fit trend for U.S. shale-oil. While it is difficult to say how much oil prices are likely to change the U.S. trend or how much oil prices could increase in general or how much the world's economy is likely to decline due to a peak in oil production, at least we can estimate roughly when a U.S. shale-oil peak oil will occur and additionally some likely general world petroleum market characteristics that will help to forecast when oil prices could increase substantially and by how much, especially once the COVID-19 pandemic or its recessionary effects subside.

The Hubbert Curve methodology employed here is contrary to the peak oil demand debate. Peak oil demand scenarios, not including COVID-19 demand side issues, are based on very volatile technology trends, particularly battery technology, whereas a Hubbert Curve, with a delineated geologic definition of the natural resource in question, is based on a theoretically grounded, and empirically verifiable, typical economic supply trend based on Reynolds (2001, 1999) and Jakobsson et al. (2012). We will also look at how other shale-oil resources in other parts of the world may evolve given that shale-oil and shale-gas resources can be complimentary in production or substitutes in production. An explanation for how and why shale-oil and shale-gas can be both compliments in production or substitutes in production is given. Also, some OPEC institutional characteristics in regard to oil prices are discussed.

The end result of this study is that based on the Hubbert Curve theory of information and depletion, the U.S. shale-oil production rate will soon reach its peak and decline. Other non-U.S. shale-oil regions will not be able to develop due to the problem of natural gas and oil often being substitutes in production rather than compliments in production. What this means is that the U.S. shale-oil peak will be the world's ultimate petroleum liquids peak in production given that all other petroleum liquid substitutes are severely constrained and/or very costly to produce, such as tar sands based petroleum liquids. This will induce oil prices to rise substantially after the COVID-19 induced recession eases. OPEC members, then, will each have an incentive to raise their government takes which will reduce petroleum supplies even more. Crucially, though, two of the world's largest oil producers, Saudi Arabia and Russia, will have an incentive to reduce their respective productions on the order of 50% each, irrespective of their ability to coordinate. With short run demand elasticities being highly inelastic, the price of oil could easily shock up to \$300 or \$1000 per barrel in real 1st Quarter 2020 prices.

In light of the COVID-19 circumstances and the potential for major oil production decline induced economic problems, looking at history may be helpful. In ancient Rome from 165 A.D. to 180 A.D. was the Antonine Plague of smallpox or measles. It may have devastated about 20% or more of the population and caused a labour shortage. Ideally this would affect the economy both adversely and advantageously. Adversely due to declining labour availability and reduced output causing recession, but advantageously due to workers gaining wages and even servants and slaves being treated better in order to keep more workers working, and in addition having some workers take over as the Lord of farmsteads and agricultural lands, when owner families died out. That is the economy in total declined due to the population decline, but the economy per person, i.e. wages, increased. What is interesting about the plague is how it happened just before the crisis of the 3rd Century. From about 200 A.D. to 300 A.D., the Crisis of The 3rd Century ensued where, as Fagan (2003) shows, wetter, cooler weather patterns became the norm devastating farming productivity. The gist of this crisis was that Rome, and specifically the Western Empire, fell economically leading to its eventually official fall in about 411 A.D. Even Ward-Perkins (2006) shows a decline in economic activity in the Western regions of Rome during this time. Therefore, Rome's concluding economy may indeed be an interesting case study for our own civilization.

This treatise, then, is an addendum to Reynolds' (2011) *Energy Civilization: the Zenith of Man*, which is a book meant as a rejoinder to Bronowski's (1974) *The Ascent of Man* and a compliment to Hubbert's (1962) *Energy Resources, A Report to the Committee on Natural Resources: National Academy of Sciences, National Research council, Publication 1000-D.* The *Energy Civilization* book is meant to show some of the cause and effect relationships between energy rises and declines vis-à-vis civilizational rises and declines. On the one hand, Bronowski's (1974) *The Ascent of Man* explains the proposition that most of what causes economic growth for humankind is the simple advancement of technology. On the other hand, Reynolds (2011), along the lines of Smil (1994 and 2005), looks at a secondary ingredient to that technological ascent which is energy and how increasing energy quality and quantity, the two important dimensions of energy usage, are important to economic growth, and where the lack thereof is an ingredient of economic decline. At this point in time, then, our civilization may well be at a precipice that will play out under multiple dimensions. This treatise will spell out the dimension in economic terms that most readers in the international Association for Energy Economics (IAEE) will be able to understand. The term "we" versus "I" is used in this treatise similar to most of Samuelson's (1941) textbook.

2. PROFESSOR DOUGLAS B. REYNOLDS

Dr. Douglas B. Reynolds is currently a full professor of petroleum and energy economics at the University of Alaska Fairbanks (UAF). He was a mechanical engineer in the 1980s as a facilities and design engineer before finishing his Ph.D. at the University of New Mexico and then subsequently teaching economics for two years in the former Soviet Union, in Almaty, Kazakhstan, in the mid-1990s. Since joining UAF in 1997, he has been working in, studying and researching energy issues in one of the most energy intensive regions of the U.S., Alaska, where wood, coal, oil, natural gas, hydro-power, geo-thermal, wind and solar energy are all used and where more energy per household is needed than in any other state. Dr. Reynolds has worked, taught and/or studied in visiting positions in numerous petroleum, developing and energy consumer nations including Kazakhstan, Norway, Mexico, Poland, Russia, China, India, Turkey, France, Ireland, The United Kingdom, Uzbekistan, and Kyrgyzstan. He served at different periods as an energy consultant to the Alaska State Legislature, the Alaska Department of Revenue and the North Slope Borough, Alaska on gas-pipeline and LNG economics, fiscal systems analysis, and inflation indexing related to Oil and Gas activities. He has published 5 books and over 70 articles in refereed professional journals, Conference Proceedings, and Conference Abstracts. He has an Academic Google Hirsch Index of 15, including two articles with over 100 citations and an article that positively dis-proves being able to use the Hotelling Rule and the 6000+ articles that cite that rule, although if his index were properly compared based on external factors, it would be higher. Further information about his profile and publications can be found at: https://scholarworks.alaska.edu/handle/11122/10605.

The ideas and theories surrounding energy economics and energy macroeconomics may need to go beyond geo-physical global warming, finance, futures prices or business decision trees. Instead, energy analysis needs to look more closely at why some types of energy, such as oil, are better suited for creating an economy than others such as solar power. This requires understanding the important mechanical engineering aspects of energy systems that determine how compliments and substitutes of specific energy types interact and not just how supply normally acts. In addition, understanding energy consumption from a vital needs perspective, rather than from a desire of results perspective is important. A simple cost benefit analysis of energy is therefore hard to do, and one needs to involve some basic physics and simple engineering to understand the true characteristics of energy and why energy is so important to a number of economic activities like transportation. Having lived where the energy source to service (well to wheel) is an everyday urgent need, e.g. when one's oil furnace goes out and someone needs to walk outside in -40 degree whether to chop some wood for the wood stove, Dr. Reynolds knows the value of energy first hand. Not only that, but Dr. Reynolds has lived and visited many other countries around the world to know their energy issues too. A true energy analysis needs to address the inherent problems the world faces as an energy intensive world economy.

II. Methods

The way economics profession has always looked at natural resources, as David Ricardo first explained, is as either a "hard-tack," non-renewable, based economy or as a "corn" (maize, wheat or barley on a farm) renewable based economy. This goes back to Daniel Defoe's 18^{th} century literary character, Robinson Crusoe, who is ship wrecked on an island with only soil available and some supplies he carried from his ship. His corn stores can be planted, grown and harvested on the island with some of the harvested seeds kept for replanting and where the cycle renews itself, i.e. where the corn is a renewable resource. The non-renewable hard-tack (a hard, dry biscuit that can be stored indefinitely), though, would be used up as it is eaten, although by using a present-value, Hotelling, social planning, maximum benefit plan, the use of the hard-tack can be maximized in value. Nevertheless, these two ideals, the "corn" and "hardtack" economies, are the basis of natural resource economics and never has any economist questioned these premises.

However, the idea of the "hard-tack" economy, as intuitively logical as it sounds, is completely different than the real world where oil is not in a boat all stored and quantifiable for the social planner to plan out its use, but rather the oil is underground and non-quantifiable. Moreover, unlike the Robinson Crusoe hard-tack analysis, there is a cost involved not just to extract the oil, which is the only aspect that economists ever seem to understand, but a cost to find the oil in the first place. Indeed no one can ever quantify how much oil there is until well into a trend of its discovery and production such that the Hotelling (1931) rule as Reynolds (2013) shows, should never be used, nor even referred to, by economists in regard to long-run planning. It is the cost of the exploration and discovery process that is completely missed within the economics literature but which is explained here and which shows the difficulty of the social planner in the short turn.

However, there is another economic phenomenon that is also difficult to understand economically in regard to oil and gas and that has to do with the economics of the extraction (production) process for oil and natural gas in tandem. Again, this subject is confusing and because of that confusion, there is a misunderstanding as to the economic potential extraction rate of the world's petroleum liquids (oil) when natural gas must be dealt with. This is explained in section 4 on the complimentary and substitutability aspects of shale-oil and shale-gas in tandem. Part of the confusion about the relationship between oil and gas has to do with the difference between conventional oil resources, in conventional petroleum anti-clines, and shale-oil and shale-gas resources within tight-sand type rocks.

3. THE THEORY OF M. KING HUBBERT'S CURVE

M. King Hubbert is controversial. Simmons (2005), Deffeyes (2001), Hubbert, (1956, **1962**, 1967 and 1982), Holland (2008), Norgaard (1990), Al Jarri and Startzman (1999), Bardi (2005), Brandt (2010 and 2007), Davis (1958), Deffeyes (2001), Kaufmann and Cleveland (2001), Cleveland and Kaufmann (1991 and 1997), Pesaran (1990), Pesaran and Samiei (1995), Rehrl and Fredrick (2005), Reynolds (1999, 2002 and 2010), Reynes et al. (2010) and Campbell (1997), among others show how a Hubbert-like trend may occur or can be used to show a peak in oil production. Nevertheless, Maugeri (2007), Adelman and Lynch (1997), Gordon (2009), Nehring (2006a, 2006b and 2006c), Ryan (1965 and 2003), Simon (1981), Wiorkowski (1981) and Lynch (2002) argue against using such a curve.

The usual idea is that the Hubbert Curve is a "curve fitting" technique, similar to how labour economists using econometrics "curve fit" unemployment statistics with the growth or decline of GDP. In both cases, there might be problems, omitted variables or alternative characteristics that make one or another model become mis-specified. However, with Hubbert's curve, the criticism is that it is not based on any theory, whereas labour market curve fitting is based on a theory. The real issue then is not curve fitting, then, it is determining what the theory is behind the Hubbert Curve. Reynolds (2010, 2009, 2002) extensively explains the criticisms of Hubbert's method and the errors inherent in those criticisms, like for example the criticism that Hubbert did not take into account technological advances, when in fact his method did consider the slow progression of technology inherent in the statistics he used. Another consideration is large one time changes in technology and large one time changes in institutions, which is also explained in Reynolds, and which can apply to any other econometric analysis of any other economic relationship phenomenon. A final consideration is defining what resources are being talked about, whether it is conventional oil, shale-oil, tar-sands oil, heavy-oil, coal-to-liquids or for that matter whale-oil. That is, one needs to define the resource being talked about. Some examples of how the theory can be shown to work are in Bardi (2005), Reynolds (2001) and interestingly using artificial intelligence (AI) with Jakobsson et al. (2012) where computer aided experimental economics are used to explain the curve.

Nevertheless, at least some explanation of Hubbert's method is in order. Non-renewable natural resource economics has traditionally, from Livenois and Uhler (1987) to Asker et al. (2019), thought of as a question of the cost of the resource and in particular the cost of extracting the resource without considering the process, and ***expected*** cost, of exploration in the first place. Rational Expectations are the key. Therefore, the way to view petroleum then is to consider a search process such as looking for whales in an ocean. Looking at the ocean from shore, there is no way to judge how many whales there are in the water until hunting for whales is actually started, but as Bardi (2007) shows, even whaling follows a Hubbert Curve. It is similar with oil. Before geologists can forecast how much oil there is, drilling must actually occur. As Hubbert (1982) says: "…. it is easy to show that no geological information exists, other than that provided by drilling... ." Therefore to understand the Hubbert Curve theory, how a search process advances has to be theorized. And to understand how a search process advances, certain terms of the process have to be defined so that the rational expectations of the process can be understood.

THE CONCEPT OF A SEASON:

In order to understand the exploration process of discerning and estimating underground, non-renewable natural resources, you have to first understand what a season is. A season is a planned period of time for exploration of maybe a year, maybe a month, or maybe even a single day. In Alaska for example, a season is the winter season where ice-roads, permits and labour are hard to come by, which means the season has to be well-planned and which means you pretty much have to stick to that plan no matter what. It is indeed very difficult to change your plans. That planned period, then, requires an exploration plan in order to be able to carry out the season's exploration. This is in stark contrast to Menard and Sharman (1975), who speculate that drilling for oil is like throwing darts at a map basically using a grid system. What they do not account for is how rational expectations and options theory makes such a simplistic proposition a money and profit losing one. After all, Menard and Sharman know something in their experiment that actual oil explorers did not know: that the East Texas oil field actually exists.

Going back to what a season is, for example, a single firm cannot simply decide in one day that it will suddenly drill one million exploration wells by the end of that same day. Such an exploration operational campaign would be impossible without first having a plan and contracted labour, capital and materials in place to be able to carry out that plan. So, you have to plan out your season. You have to contract to hire workers, to procure capital equipment and to obtain other inputs for that entire season even if it's only for a single day. If you do not plan out the season properly, then half way through it you will either have too much labour and assets or too little, and you will have to stop and waste your hired assets if they can't be used elsewhere. An inefficient plan for the season is a loss incurring proposition. The best way to earn a profit from an exploration process is to use rational expectations to minimize the costs for the plan and maximize your expected value of the outcome. This all requires you to use the information available to you at the beginning of the season, both your own internal information and information externalities you can garner from surrounding oil explorers.

Another aspect of a season is having permits, rights of way and other legal requirements in order that you can carry out your seasonal plan. The plan will look something like Figure 1. That is you will estimate probabilities of discovery based on existing information, which is the firms subjective probability curve. The best location, which is your best guess to start drilling, based on your subjective probability of success, will be the location of the first well, the second best location will be the location of the second well and so on for the entire season and given cost and logistical concerns. Because you will have little lea-way to change capital, labour and other inputs during the season, you must plan the season to an exact number of wells and follow the plan, or you will incur higher expected costs. Therefore, new information garnered during the season will only be useful for a subsequent season, and will not be useful during the current season. You will normally, with some slight exceptions and exigencies, not change your seasonal plan during the current season.

Based on the Figure 1 subjective probability, i.e. the probability your exploration company has about all possible drilling programs that you can undertake, then marginal costs for the firm will look like Figure 2 where the costs are inversely proportional to the probability of discovery of oil. That is an expected one in ten probability of discovery requires ten wells to find a good reservoir. An expected probability of one in a hundred requires one hundred wells to find a good reservoir, implying a higher marginal cost, and so on. Since the number of wells drilled is roughly proportional to the amount of discovered petroleum reserves, then Figure 2 can be a marginal cost curve of oil discovery. If it is aggregated for all firms, it gives a supply of oil discovery curve within a season.

Figure 1 The Trend of the Expected Probability of Success for Each Subsequent Well During a Season

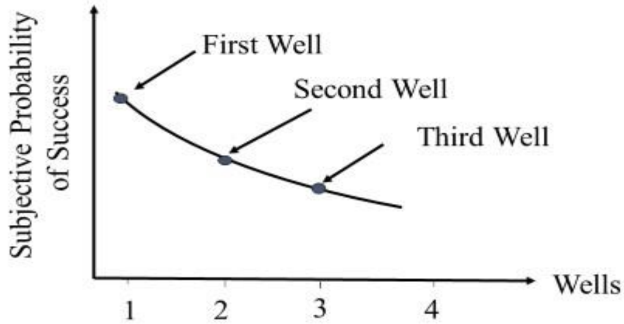


Figure 2 The Expected Marginal Cost of a Firm for the Supply of Petroleum During a Season

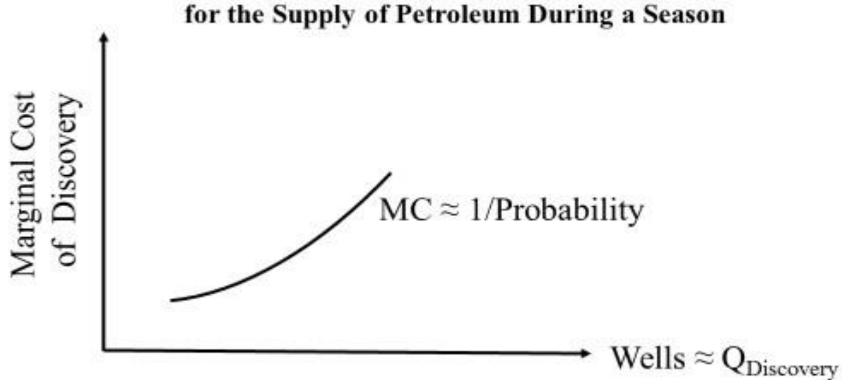


Figure 3A The Information Effect on the Trend of the Probability of Success Between Seasons

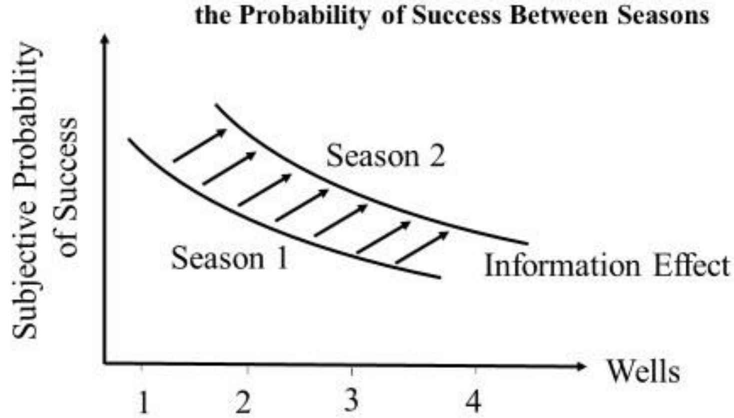
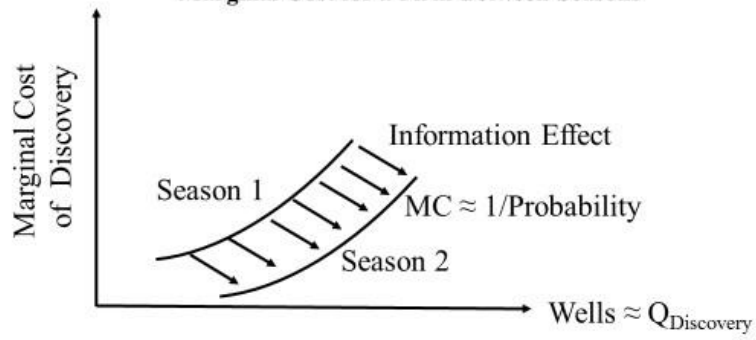


Figure 3B The Information Effect on the Marginal Cost for a Firm Between Seasons



Now normally, the better your information is, the higher your subjective probability of discovery is and in turn the lower will be your marginal costs. So, as information increases from one season to the next, your marginal costs will decrease between seasons. It is often the case that your information increases either due to information garnered by your own efforts or due to other firms' efforts that you hear about, so called information externalities. Either way such additional information between seasons can be looked upon as a shift of your Figure 1 probability curve upward or a shift of your firms marginal cost curve downward as shown in Figure 3.

One problem with underground non-renewable natural resources, though, is that by definition of the exact resource, it is a finite resource and can be used up. Therefore, during the course of exploration, there will be depletion of underground resources where by all of the potential extractable resources will be found and thus there will be a decline in availability. That is, this is not about depleting an individual petroleum reservoir, but about having less such reservoirs to find as each new one is found. This is called the depletion effect, as shown in Figure 4, and it is exactly opposite to the information effect of Figure 3.

Figure 4A The Depletion Effect on the Trend of the Probability of Success Between Seasons

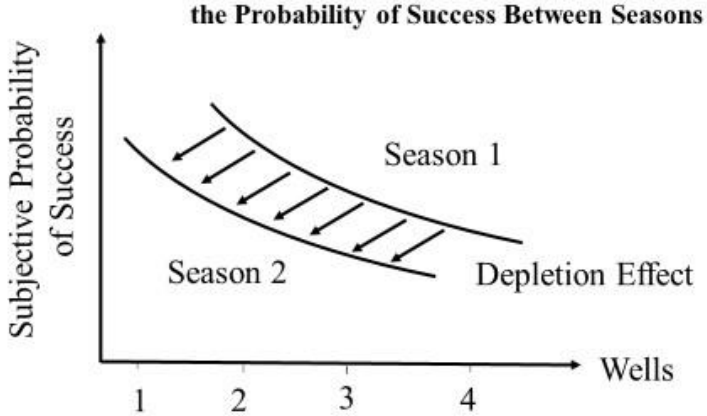
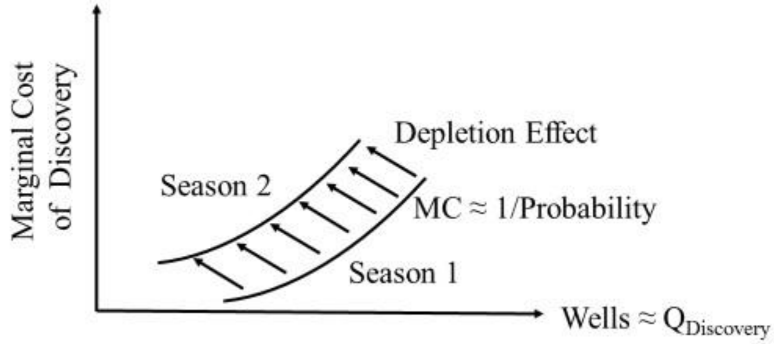


Figure 4B The Depletion Effect on the Marginal Cost for a Firm Between Seasons



ASCERTAINING THE HUBBERT CURVE:

In order to understand the basic trend that the Hubbert Curve entails, the changes between the seasons need to be understood. The question is, how do these seasonal shifts work over the long run. Based on Reynolds (1999), the information effect dominates at first because early on oil explorers are working with very little information about the non-renewable resources' location, although nothing has been depleted yet. So, any little bit of information helps hugely to increase exploration success and expand production in the early seasons where hardly any depletion has occurred. Later on, with lots of information there is so much depletion that has occurred, where many of the potential fields have been found, that there is very little or nothing left to find. This is shown in Figure 5 where the early information effect dominates at first, but then the later depletion effect dominates at the end.

Figure 5A Early on, The Information Effect Dominates the Supply of Oil Between Seasons

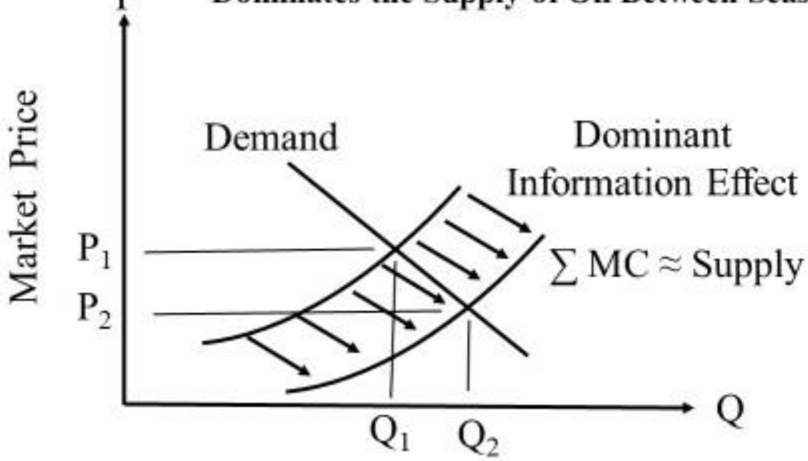
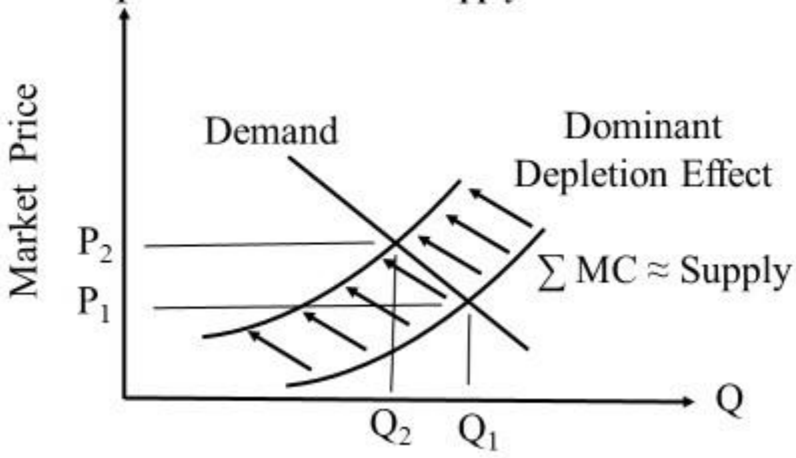
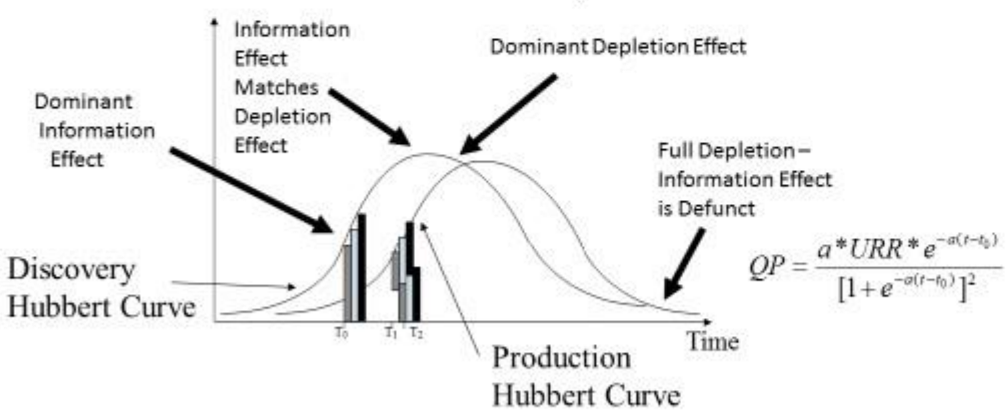


Figure 5B Later on, The Depletion Effect Dominates the Supply of Oil Between Seasons



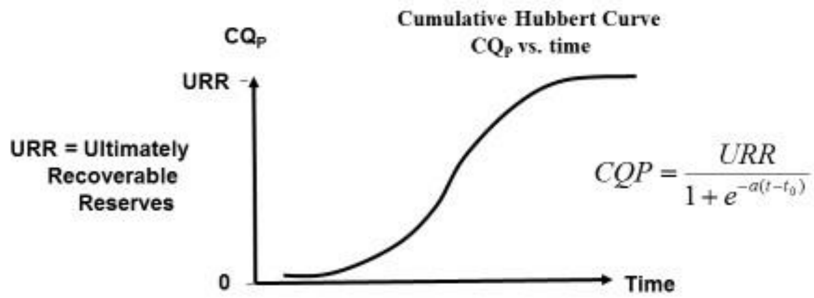
The net effect of these two, early then late, domination scenarios is that you have a tendency for an early increase, from nothing to quite a lot, in quantities discovered and then produced, followed later at a certain mid-point with both information and depletion effects equalling each other for a peak in discovery and production. Then finally depletion starts dominating for a decline in discovery and production until nothing economical to produce is left to find and extract. This can be modelled as a logistics curve equation as shown in Figure 6.

Figure 6 The Logistics Curve with an Early Rise and a Later Decline in Discovery and Production.



Also, you can show the cumulative production over time as shown in Figure 7.

Figure 7 The Cumulative Production Logistics Curve

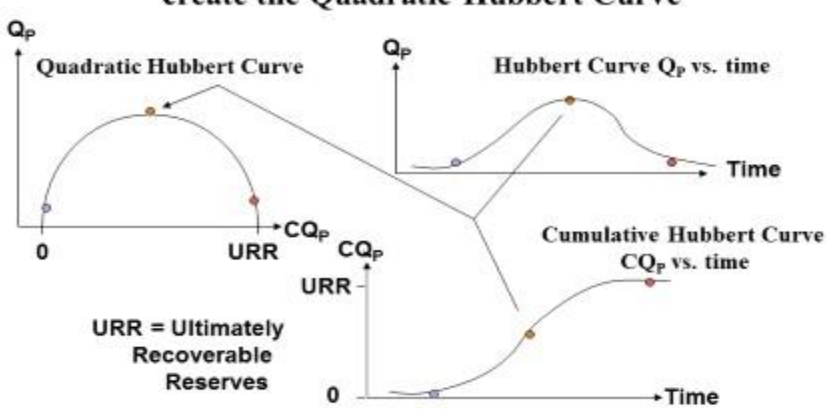


Note how Figure 6 shows the oil production trend following closely the oil discovery trend. In the U.S. for conventional oil (not shale-oil) the discovery trend was about 11 years ahead of the production trend. However, for U.S. oil-shale resources, the discovery trend is more like 11 months ahead of the production trend because shale-oil resources are quickly drained once the reserves are found and proven to exist. This makes it much harder to analyse a U.S. shale-oil Hubbert Curve using discoveries only, because the production trend is so close to the point of discovery. Therefore, one is forced to use production data only to analyse where the peak in U.S. shale-oil production will occur. Technology can change the trend, although as Hubbert (1962) explained, small yearly changes in technology are taken into account by the trend, larger changes can create multi-cycles as explained below.

CREATING THE HUBBERT QUADRATIC AND LAMBDA CURVES:

In order to better understand how the Hubbert Trend works, we can make it into a non-time dimensional curve. The way to do this is to put the logistics curves of Figures 6 and 7 together as shown in Figure 8.

Figure 8 Putting the Logistics Curve with the Cumulative Logistics Hubbert Curve together to create the Quadratic Hubbert Curve



The mathematics of the relationship is shown in Figure 9:

Figure 9 Putting the Logistics Curve with the Cumulative Logistics Hubbert Curve mathematically together to create the Quadratic Hubbert Curve

$$e^{-a(t-t_0)} = \frac{URR}{CQP} - 1$$

$$-a(t-t_0) = \ln\left(\frac{URR}{CQP} - 1\right)$$

$$QP = \frac{a*URR*e^{-a(t-t_0)}}{[1+e^{-a(t-t_0)}]^2} = \frac{a*URR*\left(\frac{URR}{CQP}-1\right)}{\left[1+\frac{URR}{CQP}-1\right]^2}$$

$$QP = \frac{a*\frac{URR^2}{CQP} - a*URR}{\frac{URR^2}{CQP^2}} = a*CQP - \frac{a}{URR}*CQP^2$$

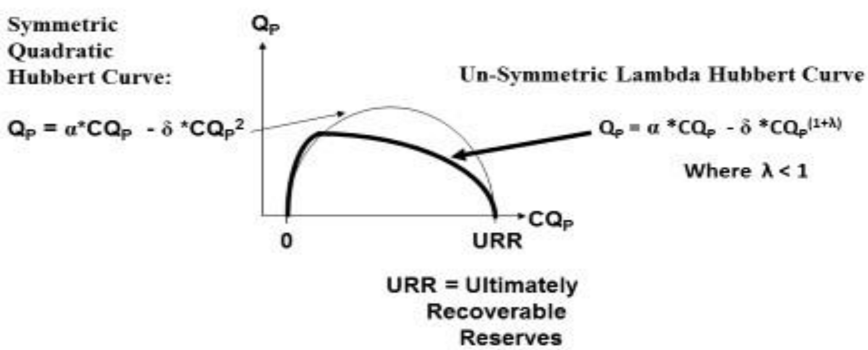
solve for $-a(t-t_0)$ in CQP and plug in to Q

$$CQP = \frac{URR}{1+e^{-a(t-t_0)}}$$

$$QP = \frac{a*URR*e^{-a(t-t_0)}}{[1+e^{-a(t-t_0)}]^2}$$

Clearly many economic forces such as permitting, land rights, government take, and other aspects of oil production will affect the trend in production, so a perfectly symmetric Quadratic Hubbert Curve may not always happen. Therefore, one other mathematical formula can capture the various trends affected by institutions, technology and intervention which is a Lambda Hubbert Curve as shown in Figure 10.

Figure 10 The Hubbert Lambda Curve
Petroleum Production (Q) versus Cumulative Production (CQ)



MULTI-CYCLE HUBBERT TRENDS:

A major criticism of Hubbert is that there can be multiple cycles of oil production trend such as the U.S. itself with the conventional Lower 48 trend and a subsequent Alaskan added trend, as Reynolds and Zhao (2007) explain, and then with the 21st century shale-oil additional trend. These types of multi-cycles can be found in Nehring (2006a, 2006b, 2006c) and Reynolds and Kolodziej (2009). Reynolds and Pippenger (2010) and Reynolds and Kolodziej, (2009) show them in Venezuela similar to Figure 11, and in the U.S. for natural gas reserves.

Figure 11 The Multi-Cycle Hubbert Curve

Interestingly, Hubbert also saw these types of non-traditional multi-cycle trends and so he consider how small examples and larger examples of physical phenomena can act similar but differently. For example if a mouse jumps off a table or if a person jumps off a tall building, will they react similarly or differently? The distance of the fall is the same relative to the height of each entity, but due to physics, one entity can survive such a fall, while the other cannot. So, the two situations are similar but different and this lead Hubbert to see that physical phenomena such as a small mine's extraction trend can look similar but different from a large area's trend. Nevertheless, Hubbert did notice small mines went through a small, large small sequence of discovery and production that lead him to look at larger regions as a way to average out small regional variations. Then, even though small regions can endure multiple rises and falls, a large region such as the entire worldwide trend averages out small regional changes.

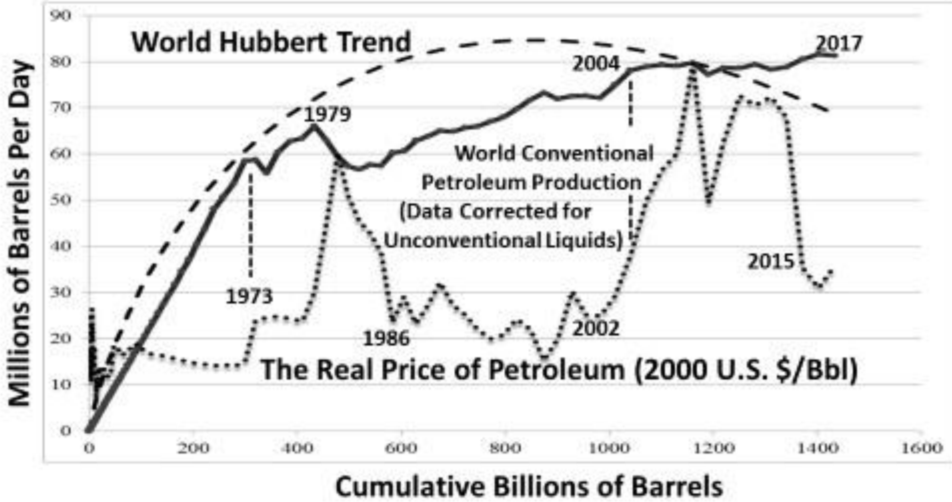
Another aspect of a Hubbert Curve is defining a resource. After all if coal can be converted into a liquid fuel as has happened in Nazi Germany and in South Africa, then does that imply coal is oil? Usually the answer is no, but heavy oil, tar sands and tight-sands shale-oil are often considered conventional petroleum when in fact they are a geologically different resources than conventional oil and they often have different cost structures, particularly based on energy return on investment (EROI) considerations as Hall (2008), Hall et al. (2008 and 1986), Cleveland (2006 and 2008) and Rock (2004) show.

So, shale-oil should be considered as a first substitute for conventional oil. Tar sands, heavy oil and coal conversion will be the next iterations of substitutes but where each has already been shown to be very expensive, not least of which is due to each of their low EROIs. Therefore, expensive substitutes will cause the same problems as a peak in shale-oil supplies. The other problem with many energy and oil substitutes is the entropy subsidy problem explained further below.

THE WORLD CONVENTIONAL OIL HUBBERT TREND:

According to Deffeyes (2001) and Reynolds (2009), the world reached its peak, or more like a plateau, in conventional oil production in roughly 2004. This is shown in Figure 12, based on EIA (2020), BP (2019) and DeGolyer and MacNaughton (1979), and where conventional oil production is separated as best as possible from other petroleum liquids extraction such as tar sands, shale-oil (tight sands) and natural gas liquids from tight sands, although heavy oil, another non-conventional petroleum product, is not separated out, and where discrepancies between stated production and actual production cannot be accounted for. Notice too, as Reynolds (2002b) shows, that the Hubbert supply curve is highly inelastic. The estimated Hubbert Curve though starts to show some deviation from actual production after about 2009 which could suggest that the Hubbert Curve doesn't work well or more likely that the data set is not a clean data set for true conventional petroleum resources.

Figure 12 The Hubbert World Lambda Trend and Real Price; Petroleum Production (Q) versus Cumulative Production (CQ)



Looking closely at Figure 12 gives a good overall perspective of how the world's oil market has progressed over the years, and that can be contrasted with Maugeri's (2007) important and contrasting historical take on oil. For example notice just before 1986 how oil prices plunged, much of the plunge of which actually happened in the 1st quarter of 1986. Of this plunge, Maugeri states, "in 1986 another huge wave of over production led to a new oil price collapse." But looking at the diagram, it was the consumption that declined below the long term trend in the use of oil that created a huge decline in the world oil production and that in turn forced oil producers including Saudi Arabia to reduce the price of oil. The trend in oil consumption had been increasing at about a 10% per year pace every year for decades and then the trend was reversed during the high oil price years that began in 1973 and culminating in a number of oil conservation effects that finally came about after 1979 but which continued to push down demand through 1986. And while the ability to change demand is good, oil prices still certainly have an adverse effect on the economy as Hamilton (1983and 2009) clearly shows. Also important is that the pace of wage increases for the lower half of wage earners in most the OECD countries has flattened since the 1970s. Clearly, then, this suggests that the oil market has an effect on the world's 20th and 21st centuries' Globalized Civilization's economy. Note, the 2015 price plunge also looks only to be caused by another supply side increase, specifically due to U.S. shale-oil production increases, which are not shown in Figure 12. However, and not well understood is a potential large decrease in demand from China that may not match official published statistics shown.

On the one hand, one might believe that a close approximation of a Hubbert Curve is good enough for understanding the estimated supply maximum of the total conventional oils. On the other hand, by knowing the true conventional Hubbert trend with a clean data set, it would be easier to understand the size of the petroleum demand to conventional oil supply gap that the world is likely to face. Once we estimate a Hubbert trend for U.S. shale-oil as a separate estimation and then consider the world's likely demand scenario given the current COVID-19 recession, then it is easier to know how much petroleum alternatives will need to be able to come on line to replace oil. This potential supply gap can then better help in estimating future oil prices and non-conventional petroleum needs. More likely than not, there are deep discrepancies in the world's conventional oil production data that probably are too difficult to uncover. The most likely scenario, though, is that the estimated Hubbert Curve trend shown is very close to the real conventional petroleum crude oil production limit.

4. SHALE-RESOURCE SUPPLY THEORY: COMPLIMENT VS. SUBSTITUTE IN PRODUCTION

One of the most subtle concepts in all of economics, is the difference between a substitute in production and a compliment in production, but it is that concept that will determine the world supply of shale-resource based liquid petroleum fuels at any given time. A substitute in production is where only one item or another can be produced at any given time. This is like when a farmer must choose to produce either maize (corn) or wheat on any given hectare of farm land. Either maize substitutes for wheat or wheat substitutes for maize but both cannot be produced simultaneously. Alternatively, beef and leather are compliments in production. The more beef you produce, the more leather you simultaneously produce. No matter which product you decide to produce, more of one output automatically produces more of the other output, and where both outputs have at least some value.

Oil and gas also have a production relationship. However, with oil and gas the relationship can switch from being a production complimentary relationship to a production substitutionary relationship. Such a strange phenomenon happens in almost no other industry. Consider oil and gas as compliments in production. If you go into a shale-oil region and you already have natural gas pipelines nearby in which you can readily market your natural gas, as they do in Texas, then as you produce oil and gas together both can be sold. They are complements in production to each other.

However, if you go into a shale resource region and there is no natural gas pipelines nearby, or even if the natural gas reserves of the region are very high such that there is no need to produce more natural gas because too little natural gas can be taken away from the region, then the natural gas is a nuisance in the production of oil, i.e. it is a substitute in production, such as in Alaska. You have oil and gas available but you do not want both. Thus, since you only want the oil, and even a small bit of natural gas must be dealt with through flaring or putting the gas into an expensive storage unit or underground storage reservoir, then it may be the case that the natural gas inhibits you from producing the oil. Any small amount of gas with the oil causes disruption of the oil production process, i.e. they are substitutes in production. The substitution situation happens because getting at the oil requires dealing with the natural gas which is an explosive substance if not properly dealt with. Flaring is the easiest, cheapest way to deal with it, but that creates some carbon emissions and is often of major concern due to the perceived wasting of resources. So the cost of dealing with the natural gas can be so high that it precludes the ability to produce oil, which means they are substitutes in production. And since there is almost always a little natural gas within the shale-resource, then it is very difficult to produce oil exclusively, unless the price of oil is very high.

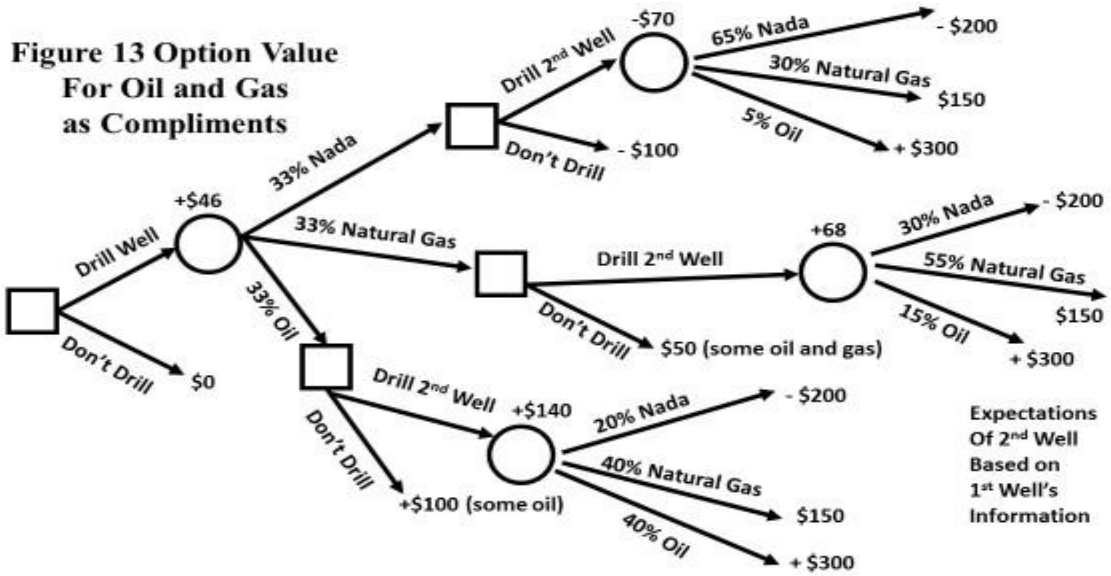
It is at this point, that most petroleum production engineers think that the simple flaring of the natural gas provides the solution to this problem and with little or no safety issues. However, production engineering is one side of the problem, but the other side of the problem is the actual process of exploration in the first place.

OPTION VALUE:

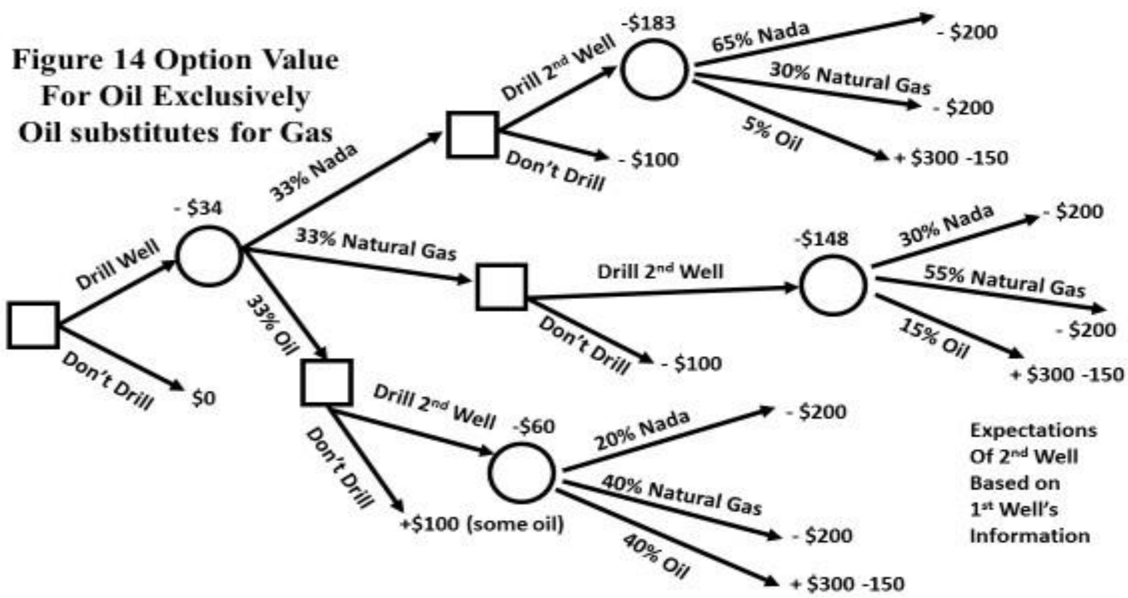
The way to look at oil and gas exploration is in terms of an option value in operations management terms. Using a simple decision tree, a first decision with two outcomes will lead to further decisions, outcomes and probabilities that all must be estimated in a backward direction from a final set of production profitability's. Thus, the first decision going forward is an option whose value is determined by subsequent information. If in fact you suspect the value of the subsequent information is low, i.e. that there is going to be a substantial amount of natural gas found even after a first well is drilled that says that there may be a lot more liquid petroleum than natural gas, nevertheless, you still may not buy the option, i.e. you won't drill the first well, because of what you might find in the next round of drilling.

Consider for example three initial speculative outcomes for a first well: a 33% probability of mostly nothing, a 33% probability of mostly natural gas and a 33% probability of mostly liquid petroleum. However even if mostly liquid petroleum is found for a first well, what does it imply for a second well? The next subsequent well may still only have a less than 50/50 chance at good oil prospects. And with a lot of heterogeneous shale-resource prospects, one shale field right next to another can be completely different. So it is much harder to use and follow geologic trends when you are dealing with shale resources. So the real probability over the course of a set of exploration wells is probably lower than 33% for liquid petroleum, which means a very high price for oil is needed to endeavour to look exclusively for heavier petroleum minerals.

For the U.S., you have a completely different probability distribution as now both oil and gas give value and therefore your option value is so much higher than it is for an exploration process that is exclusively looking for a liquid petroleum resource. In a complimentary case, the natural gas outcome is valuable in and of itself because natural gas pipelines already exist often within a hundred miles of any U.S. shale-oil resource discovery in the Lower 48 contiguous states. The fact that you can produce and sell natural gas as well as oil creates a positive prospect value out of what would be a negative one.



Notice in Figure 13, if you are looking for oil and gas such that any natural gas found becomes a valuable asset option, then you will get a positive information value for the option to drill the first well. In Figure 14 below, though, you may end up with a negative option value for the first well, because only oil is worthwhile, and because even if you can find mostly oil on the first well drilled, nevertheless, there will be some natural gas that you will have to contend with which will lower the value of the oil. Furthermore, even if the first well does find a lot of oil, it does not mean that a second well will only find oil. That is the natural gas is an expensive impediment to any further oil exploration you want to do because you will inevitably find both some oil and some natural gas. And again, the natural gas is a very volatile product that can blow up and cause problems. So, the gas has to be stored as it comes out, an expensive prospect, or be flared, a politically daunting prospect since it appears to be so wasteful.



III. Results

This section gives an estimate for the U.S. shale-oil trend and explains the theoretical explanations for which type of Hubbert Curve trend it is following. Then, an oil price forecast is given. While it is impossible to predict a price accurately, it is at least possible to give some scenarios. Clearly as the COVID-19 virus shows, and even as the entire shale-oil phenomenon itself shows, large changes to the supply or demand of petroleum can happen fast. Nevertheless, it is good to understand some of the scenarios that are possible and to give at least some prediction of what could be in store for the world's petroleum markets. This also requires an understanding of the economic power of energy in general and oil in particular, of OPEC and its relationship with Russia and of the socio-economic relationships between oil, OPEC and the world's economy. A Schwartzian (1991) futurology set of prediction scenarios is also given.

5. U.S. SHALE-OIL *TÉNDANCES*

Looking at U.S. shale-oil data, it is important to separate conventional oil from tar sands (misnamed as oil sands), shale-oil or for that matter whale oil. These all occur within geologic time frames that are often magnitudes different, e.g. one million years old versus ten millions years old. To call shale-oil as conventional oil, which is normally considered to be petroleum from a reservoir anticline, is inappropriate. The U.S. EIA (2020) shows specific tight oil (mostly shale-oil) data separate from conventional, anticlinal reservoir oil. The EIA shale-oil data, then, is used to forecast trend estimates as shown in Figures 15 to 17 for a Quadratic Hubbert Curve, a Lambda Hubbert Curve and a straight line (non-Hubbert Curve) respectively. Readers insisting on a full slate of econometric tests and variable inclusion statistical tables are free to go to the EIA's data set and run them all for themselves.

The question is, with so few data points and what looks to be a random walk of the data, in all probability related to the change in oil prices in 2015, then it stands to reason that the relationship between cumulative production and current production could be indeterminable. If a simple straight line estimate is used, we get an r-squared of 95%. If a quadratic functional form is used, we get an r-squared of 96%, and if a Lambda Hubbert Curve is used, we find the best lambda at 0.005 and an r-squared of 97%. The supply looks to be inelastic with respect to price, but the one bump in the data happened one year after the downward price shock, so it is possible that price has a one year delay on production. This makes sense since discovery was happening at a certain trend just before the downward price shock, then discovery efforts went down at the time of the shock. However, the existing shale-oil discoveries were subsequently developed and produced, increasing the production trend right through the price shock. Then after a year, the lower discovery rate finally affected the production rate. Nevertheless, supply is still relatively inelastic with respect to price at a short run elasticity of about 0.15. Putting the one year delayed price in as a variable increases all r-squared's to 99%, with the Lambda Hubbert Curve slightly better than the Quadratic Hubbert Curve, which is slightly better than the straight line.

Figure 15 The Hubbert Quadratic Curve Estimate
Petroleum Production (Q) versus Cumulative Production (CQ)

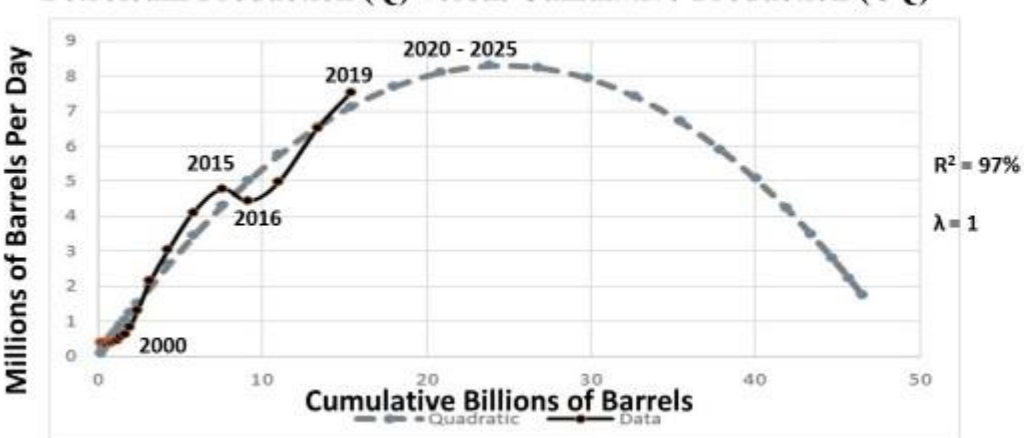


Figure 16 The Hubbert Lambda Curve Estimate
Petroleum Production (Q) versus Cumulative Production (CQ)

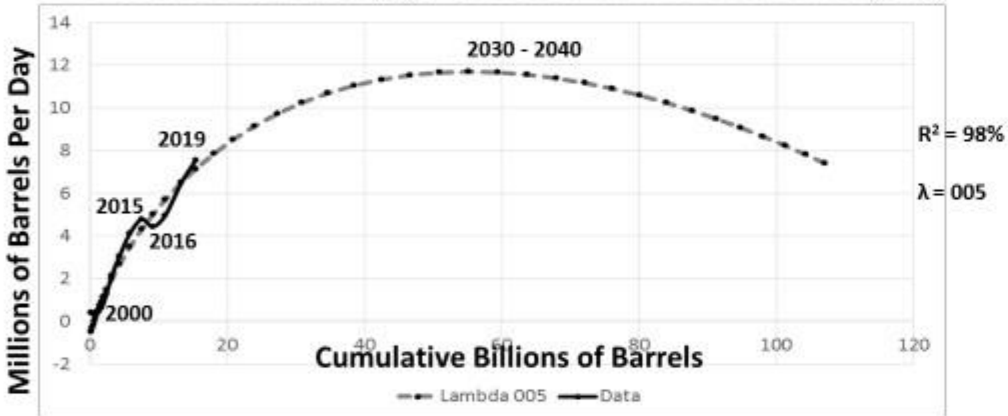
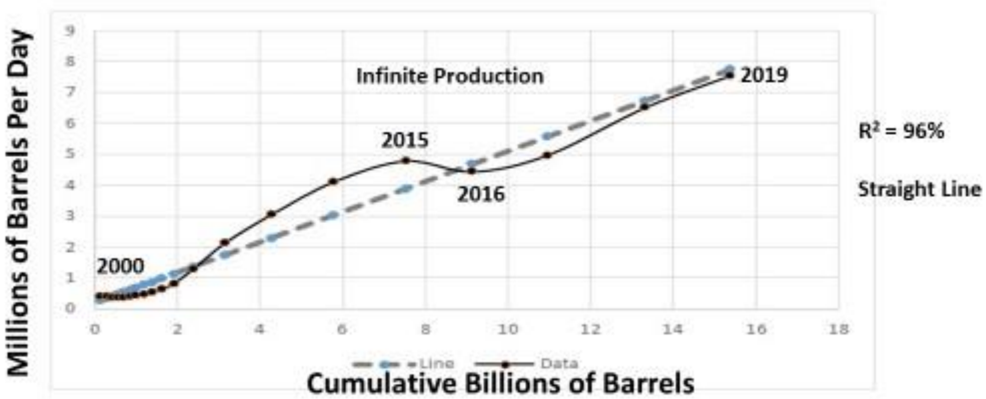
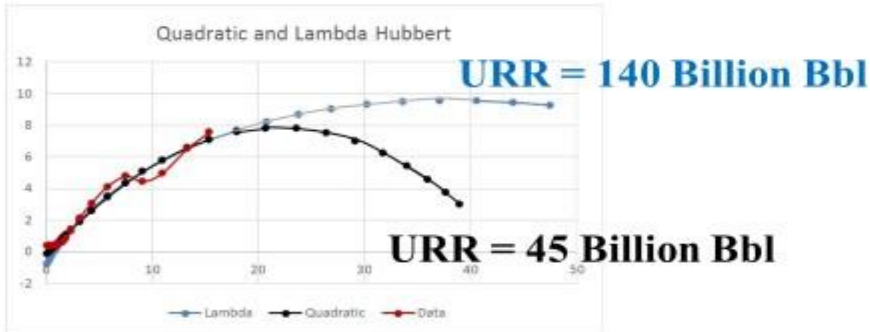


Figure 17 The Straight Line Estimate
Petroleum Production (Q) versus Cumulative Production (CQ)



The potential peaks in production for the Quadratic Hubbert Curve is from 2020 all the way to 2025. For the Lambda curve, with various econometric estimations, the potential peak is anywhere from 2030 to 2040. The Ultimately Recoverable Reserves (URR) for the Quadratic Hubbert Curve is around 50 billion barrels of oil or less, but for the Lambda Hubbert Curve it is closer to 130 billion barrels of oil or more. See Figure 18. The straight line shows an implausible infinite amount of oil. So the data of and by itself cannot definitively give a peak in production timing. However, using some reasoning we can give a prediction.

Figure 18 Comparing a Hubbert Quadratic Curve to a Hubbert Lambda Curve for U.S. Shale-Oil



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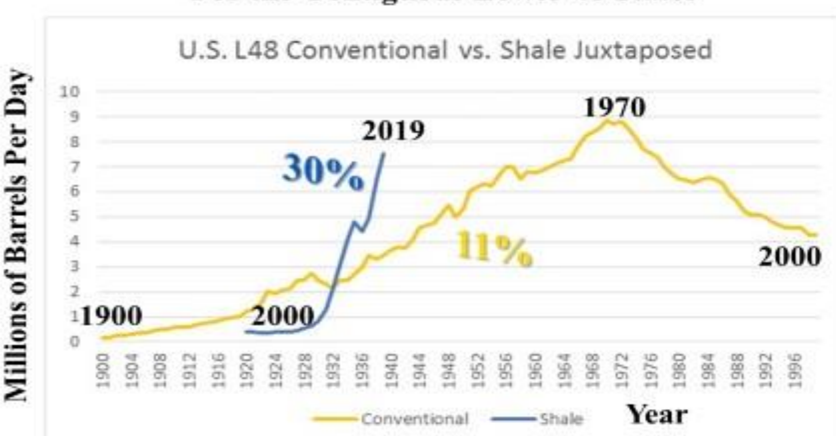
Notice Figure 19 below, where a juxtaposition of U.S. shale-oil with U.S. conventional oil for the Contiguous Lower 48 states shows a fast increase for shale-oil and a slow increase for conventional oil. Why should this happen? One reason could be technology where the current technology is so good that it has become easier to find the reservoirs of oil. Another idea is that the oil (and gas) explorers are looking for two commodities simultaneously, oil and gas. This brings up a third idea discussed above which is that because there already exist natural gas infrastructure in most of the U.S. Lower 48 contiguous states, and therefore with two potential commodities to sell, the search process is made more efficient. That is by searching for two commodities instead of just one, it increases the success rate of the search process for the oil side. Also, the institutions in the United States with free markets and private land mineral rights ownership could be a factor, although even in the U.S. there have been regulations on oil production such as the Texas Railroad Commissions oil production restrictions.

Figure 19 Comparing U.S. Shale-Oil to U.S. Conventional Oil For the Contiguous Lower 48 States



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Let us, though, reconsider the information effect and the depletion effect from above. Now while conventional oil and shale-oil are from different geologic stratums, nevertheless much of the geologic knowledge from the conventional oil search is useful for the shale-oil search. This means that there is an added boost to the information effect for the U.S. shale-oil exploration along with technology and natural gas infrastructure, making the production increase of 30% per year plausible.

Unfortunately, while information, natural gas infrastructure, institutions and technology are undoubtedly at play for the quick increase in production, it does not stand to reason that there will be a longer lasting reserve base of the shale-oil resources relative to how the conventional oil production trend went. Indeed, the overwhelming evidence is that shale-oil production well declines are extremely quick relative to conventional oil. That means a quick rise in production is more likely than not to be followed by a quick extraction decline trend, i.e. a Hubbert quadratic trend is the most likely scenario based on engineering and economic reasoning. This is especially true since the U.S. institutions, with multiple property rights and multiple private oil and gas explorers and producers, make a U.S. trend go up and down much quicker relative to trends in other countries where only one company or one government entity runs everything, or at least decides everything. Other countries would normally have a Lambda Hubbert Curve trend due to their more restrictive institutions, but the United States should have a Quadratic Hubbert Curve trend even in spite of some restrictive regulations. That means oil markets will quickly become tight once U.S. shale-oil peaks and declines, putting a lot of market power into the hands of OPEC as explained below.

Note, also, how there is a bump in the trend of the data around 2015. That is when oil prices dipped from $100 per barrel to $50 per barrel. The usual idea is that this dip in price must have affected production or at least the trend in production and it looks to have done so. However, looking closely at the literature, for the oil industry here is probably what happened.

First, oil prices started down in late 2014, so basically they were low all of 2015. Plus in late 2015, they started to go even lower still for a few months into 2016. However, due to previous exploration efforts, a number of oil reserves already discovered were allowed to be developed, where discovery and development of shale-oil is practically the same thing. This shows up in the data as a one year delay in the production trend vis-à-vis the price of oil. That is many discoveries in 2014 continued on to development in 2015, whereupon the lower prices of 2015 induced lower exploration and subsequently lower development in 2016. However, the industry also was very competitive in the U.S. and therefore the various shale-oil and shale-gas producing companies managed to reorganize and restructure their costs downward with better use of technology during 2015 and 2016 with more efficient labour and ever cheaper capital. The end result was that the re-contracting of labour and the changes in capital all created a reduction in the price of business. Therefore after a slight delay in production and presumably exploration efforts, the restructured industry was able to restart where it left off and continue its relentless upward trend in production. So the price change caused more of an industry restructuring interval rather than a complete change in the true trend. Indeed if figure 15 is re-estimated only for data up to 2015, you get a similar Quadratic Hubbert Curve and with a similar peak as early as 2020 similar to the trend shown in Figure 20A. However, with updated data as of March 2020 using January 2020 data, it looks as if 2020 could be the peak year as hypothesized in Figure 20B.

Figure 20A The Hubbert Quadratic Curve Estimate Pre-2016
Petroleum Production (Q) versus Cumulative Production (CQ)

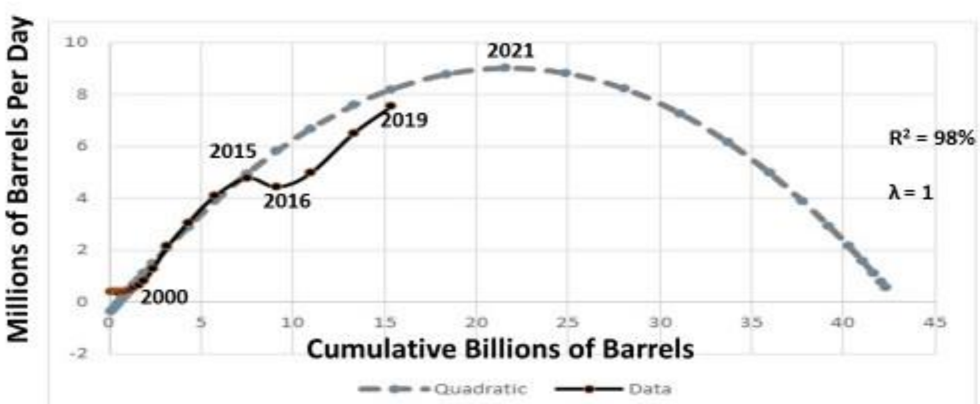
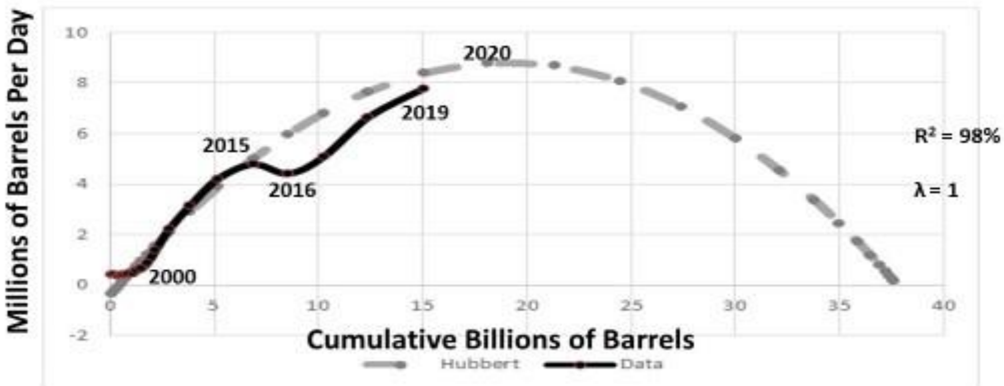


Figure 20B The Hubbert Quadratic Curve Update Pre-2016 Petroleum Production (Q) versus Cumulative Production (CQ)



Nevertheless, to expect that the U.S. will follow either a straight line production trend of Figure 17 or a Lambda Hubbert Curve trend of Figure 16 is highly unlikely. Based on economic theory and reasoning, including the fact that the U.S. Lower 48 has some of the most free market institutions anywhere, then the most probable date of peak U.S. shale-oil is within a year or three.

THE WORLD OIL ERA:

One of the most interesting debates in all of economics is the debate surrounding the scarcity of natural resources versus the ability of an economy to grow, where the debate is often termed "Scarcity and Growth," which is also the terms or some of the words used for the titles and concepts of Meadows et at. (1972 and 2004), Reynolds (2002), Cole (1973), Hall and Klitgaard (2012), Smith (1979), Barnett and Morse (1963), Simon(1981) and Simpson et al. (2005). The gist of the debate in terms of petroleum is that once crude oil reaches its peak, there will be a decline in the world's economy over the long run, and separate from COVID-19 short run considerations, although maybe not if technological change is forceful enough. Within this wider debate and in regard to petroleum in particular one can analyse specific historic eras of petroleum production history to discern certain characteristics of market influencing entities within the petroleum market vis-à-vis the world economy. For example as Reynolds (2011) identifies, there is the American Oil Era dominated by the United States (U.S.) of America's oil resources and by U.S. oil companies which lasts from about 1880 until 1973.

In 1973, the oil market is dominated at the margin not by OPEC but rather by Saudi Arabia, although certainly Iranian oil supplies were also an influencing factor at the margin. So the next Oil Era from 1973 until 1981 is the Saudi Arabian Oil Era. By 1981, though, with a softening of oil demand, Saudi Arabia could not control the market without more help. So it is here in 1981 that Saudi Arabia worked with OPEC more forcefully, although actually less effectively, as Loderer (1985) explains, to change the petroleum market. Therefore after 1981 is the OPEC Oil Era. The OPEC Era lasted from 1981 until 1988 and although it sounds like a forceful period, the members had more infighting than not. This Oil Era saw more reductions in oil prices than increases and any agreements that OPEC made often dissolved within six months to a year making the period look like a roller coaster more than a freight train.

Then in 1988 and even with OPEC strategic give and take continuing on, nevertheless a very unusual set of circumstances made a behind the scenes influence on the oil market having to do with the fall of the Soviet Union and in particular Russia's oil production decline and resurgence. So from 1988 until 2005 is the Russian Oil Era, where Russia had a lot of leverage on the oil market directly and indirectly, both due to a decline and resurgence in production and a decline and resurgence in demand. Finally in 2005, world conventional crude oil reached a plateau of non-increasing production. The plateau as Figure 12 shows is difficult to accurately depict as other unconventional petroleum sources are mixed into the world's petroleum data such as natural gas liquids from tight sands, shale-oil liquids, tar-sands liquids and other unconventional liquid petroleum resources. In addition, there may be some misreporting of production, consumption and stocks so it is difficult to get hard and fast data sets over the years. Nevertheless, from 2005 onward can be considered to be the Hubbert Oil Era until probably this year 2020.

The Hubbert Oil Era then can be defined as a peak, or at least a plateau, of conventional oil production given the existing world's petroleum market institutions, such as national oil companies that tend to limit exploration and development. It also includes the surge of shale-oil production as a secondary petroleum market supply source although with the shale-oil extraction costing roughly three times the real cost of conventional oil production that was averaged over most of the 20th century. This is slightly different from Reynolds' (2011) definition of the Hubbert Oil Era that did not include shale-oil, a point of controversy in that the shale-oil added petroleum supply was certainly unpredicted by most energy analysts. Indeed, it is that point of the unpredictable nature of the U.S. shale-oil revolution that has everyone saying there is probably another technology side surprise, or even another COVID-19 like demand side surprise, that will re-change the markets. Nevertheless, the extra shale-oil supply even as relatively expensive as it is, kept the world's economy on track for continued economic growth, thus giving the scarcity and growth technology centric arguments renewed power. Although to be sure, on the demand side we have seen oil and economic growth go hand in hand for well over a hundred years, and on the supply side, counting on more shale-oil like surprises seems an inadequate strategy.

Note, Pooley and Tupy (2018) take up the scarcity and growth debate as well and come up with some indexes to measure the amount of GDP used, as a cost basis, to obtain certain natural resources. The analysis they use, though, is a very subtle argument in that they strategically use the year 1980 and 2017 for the definitional start and end dates of all their indexes. While to the non-professional it seems like those dates are two arbitrary dates on two sides of an economic era, it was in fact deceptively done. The reason 1980 is not a good year to use compared to say the year 1970 was because real oil prices, and even oil prices measured in any particular metric, such as average wages, went up substantially in that decade of the 1970s and ended up roughly four times higher in 1980 than in 1970. Then from 2014 to 2017, oil prices declined by more than half. Thus, the Pooley and Tupy conclusion might be completely different if they used 1970 and 2014 as the start and end years of their analysis. What is interesting is that the price of oil affects other minerals in terms of mining extraction costs, transportation costs and processing costs of minerals. Even farming and renewable resource costs are affect by the price of oil. So by choosing a relatively high cost oil year for the beginning date and a relatively low cost oil year for their end date, it causes all other natural resource costs to be relatively high in 1980 and relatively low in 2017, completely independent of technological trends. In general as Hamilton (1983 and 2008) has shown, the price of oil greatly affects economic performance and it is that fact that needs to be emphasized.

Nevertheless, we are close to, as of 2020 and certainly in lieu of COVID-19 demand side disintegration, a new Oil Era which can be called the World Oil Era. The World Oil Era while it is defined by the U.S. shale-oil peak and decline in production is nevertheless called the World Oil Ear because of the lack of ability for non-U.S. (world) shale-oil resources to be produced within the era due to the substitution in production problem explained above. It is not that non-U.S. shale-oil will not eventually be produced, it is just that those world shale-oil resources will require much higher oil prices to be produced than those of the early 21st century of about \$100 per barrel in real 1st Quarter 2020 dollars. So we are probably as of 2020 in the World Oil Era although there is still a chance of another Oil Era yet to come.

The final Oil Era as explained in Reynolds (2011) is the Persian Gulf Oil Era. This would be where a political or a military disruption occurs within, between or around one or another Persian Gulf oil producer or oil producers that would potentially reduce oil supplies even more than a natural oil production decline rate. Such an occurrence would normally be subdued by the world's military establishment but could happen none-the-less.

6. PRICE EXPECTATIONS

In this section, we look at forecasting the price of petroleum. While the price of crude oil is not the same as the price of energy in general, nevertheless, petroleum is physically intertwined with the supply chain of all energy sources and their energy services. Therefore, it is important to at least tangentially understand some of the relationships between petroleum and energy in general and to understand that the price expectations for petroleum will affect the price expectations for all energy types and vice-verse. In this section, though, we concentrate on the price of oil more specifically than the price of energy. So, we will start out by looking at the idea of peak demand for oil. Then we have to understand energy more generally with something called the Energy Utilization Chain (EUC), then Energy Grades and then the concept of the Entropy Subsidy. This will help in creating an overarching energy systems relationship along the lines of Hall et al. (1986) and Hall and Klitgaard (2012). Next we will look at oil demand side issues especially during the COVID-19 induced economic recession. Then some of the COVID-19 macroeconomic demand side issues will be delved into. An analysis of OPEC and its institutional framework will be looked at. Then we will analyse Russia and its likely oil production and institutional characteristics which will lead into a further economic analysis of the Saudi-Russian oil market game-theoretic relationship. Finally, we give a Schwartz (1991) like long view, forecast scenario.

PEAK DEMAND:

The world is faced with some very serious problems right now that are intertwined with the petroleum market such as the emissions of global warming inducing greenhouse gases, the COVID-19 induced recession and developing world poverty. For now, though, consider only the global warming CO2 emissions problem. One idea in regard to that problem is that a number of electricity based technologies, and in particular the battery based electric storage technologies, are starting to become so cost effective that indeed the world is on the verge of a peak in the demand for oil, notwithstanding the issues with COVID-19. That would mean that after the COVID-19 problems are resolved, that oil prices will stay low, say under $50 per barrel in real 1st Quarter 2020 dollars and that the world will consume less and less oil, i.e. have a peak in demand.

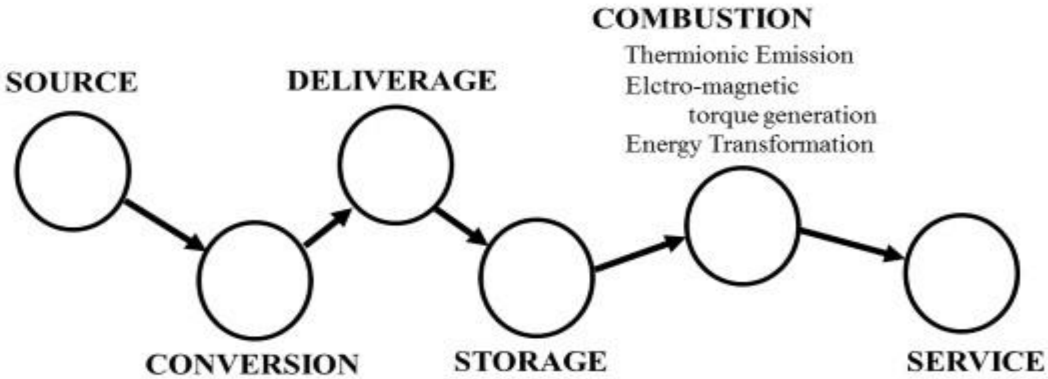
However, the concept of peak demand is more complicated than it at first seems because of the way in which industry depends on oil directly and indirectly, which is explained in sections below. For example in the early 20th century the U.S. and other countries went from a horse and buggy dominant local transportation framework to an internal combustion engine (ICE) automotive dominant local transportation framework. So now based on that characteristic evolution, it is assumed that the 21st century will change from an ICE automotive dominant local transportation framework to an electric vehicle (EV) or hybrid electric vehicle (HEV) dominant local transportation framework in a similar changeover as happened in the early 20th century's horse to ICE car framework change.

However, there are many differences between the two proposed trends. For example in the early 20th century, there were no small, cheap horses available, other than miniature Shetland Pony horses which were not useful for work and travel, where as in the 21st century we have motor scooters, small two cylinder cheap cars (like the Tata Nano in India) and very powerful Sport Utility Vehicles (SUVs) that EVs and HEVs can't substitute for very readily the way ICE vehicles could for horses and buggies back in the early 20th century. Jet planes are very cost effective, time value of money saving, fast travel per person mile that electric planes can't possibly approach in value since electric planes are constrained to propeller driven aircraft. Large cargo trucks, mining machinery, farming machinery and so on are just not very conducive to electric battery powered vehicles compared to ICE vehicles.

THE ENERGY UTILIZATION CHAIN (EUC):

Economics is about markets. Whereas when prices rise, the incentive to produce more increases, nevertheless on the other side of the transactional analysis those same rising prices cause a desire to buy less. However, going back to the supply side, there needs to be just a bit more sophistication in the economic analysis in order to understand some of the engineering challenges of energy that create less substitutes and that are more often than not glossed over by economists, many of whom have not had a lot of engineering background. But a simplification of the engineering of how the supply and demand works can be complicated, but it can be accomplished by using an energy utilization chain (EUC) as shown in Figure 21. The EUC shows the well-to-wheel or source-to-service route of energy. That is you must look at energy as a chain of stages from where the energy originates from, to where the final service of that energy is provided. The chain, based on Reynolds (2000) EUC but elaborated here, shows the important aspects of how energy gets to its final use. Note, combustion is considered parallel to thermionic emission or electro-magnetic torque generation when electric energy is transformed into a useful physical phenomenon such as light, computational power or kinetic energy.

Figure 21 The Energy Utilization Chain (EUC)



While most energy economists when looking at Figure 21 place great emphasis on the source and the service with some minor acknowledgments on the importance of the conversion and the combustion (or thermionic emission or electromagnetic torque generation) processes, there is very little emphasis on the deliverage and the storage of renewables other than to acknowledge them as technological challenges. These two parts of the chain though are such high cost provisions that they will inhibit renewables for a long time to come. What the deliverage and storage problem really means is that, other than for conventional oil and coal mechanical systems, most other energy systems will need to be used close to the source of energy and close in time to the creation of the energy which is exactly the opposite to the physical processes of the Industrial Revolution (1709 – 1850) and the 2nd Industrial Revolution (1890 - 1950) that created such phenomenal economic growth. In other words, those two incredibly successful economic eras were as successful as they were by allowing long distances from source to service (well-to-wheel) and a long time from extraction to combustion which is the exact problem with renewables that economists are glossing over.

ENERGY GRADES:

Different energy resources have different characteristics called energy grades as explained in Reynolds' (1994) idea of energy grades, and Smil's (1991) idea of power density. The concept of energy grades is so central to the global warming debate, that it is alarming how little it is mentioned. After all, over the last several centuries, the world's economy, its population and its energy use was growing exponentially. These are all related phenomenon. So in order to continue such growth we would normally expect that the greater use of energy is needed. Suddenly, there is an idea, astonishingly enough, that we can continue this growth but with energy that is renewable, i.e. with lower energy characteristics. Yet looking closely at growth over the last few centuries, it has been caused by non-renewable fossil fuels. Why? Because the characteristics of fossil fuels are so much better than the energy characteristics of renewables.

For example, the industrial revolution went from wood to coal for making steel which allowed for economies of scale in energy extraction, with mining, and steel making, with the modern steel mill, foundry and forging plant, which in turn cut the cost of steel by a magnitude or more. Once steel is cheap, that allows for all sorts of uses like steam engines, rail lines and bridges not to mention great tall buildings. The second industrial revolution went from a solid state energy, of coal, to a liquid state energy, of oil. This allowed the industry to move from an external combustion engine with steam power, i.e. a steam locomotive, to an internal combustion engine using direct combustion of a fuel inside the engine as in an automobile engine. The power to weight ratio gain for the engine was enormous and the storage weight and storage volume of the fuel was reduced allowing independent vehicles that carry the energy source to carry less, increase their travel range more and indeed augment their performance, such as with jet planes.

The problem with renewables is that they require a high cost deliverage system with power lines and a very high cost storage need. While electric motors can gain some combustion (energy transformation) efficiencies, nevertheless the storage and deliverage costs are relatively high. The world has never managed to successfully have a growing economy by transforming to a lower grade energy resource in the past. So the idea that we will have economic growth and simultaneously switch to a lower grade energy resource does not make engineering-economic sense.

Energy Grade Table

Energy Resource	**Weight Grade (BTU/lb)**	**Volume Grade (BTU/ft^3)**	**Area Grade (BTU/Acre)**	**State Grade**
Oil	20,000	1 million	10 - 1,000 Billion	Liquid
Natural Gas	24,000	1000 at std 177,000 at 3000 psi	10 - 1,000 Billion	Gas
Coal	8,000 - 13,000	350,000 - 700,000	10 - 1,000 Billion	Solid
Oil Shale	up to 2,000	200,000	10 - 1,000 Billion	Solid
Uranium	N/A, field	N/A, field	Trillions	Field
Wood	8,000 dry	250,000	1 - 5 Billion	Solid
Ethanol	11,500	560,000	Made from grain	Liquid
Methanol	8,600	425,000	Made from Natural gas	Liquid
Hydrogen	63,500	325 at std, 120,000 when super cooled	made from electricity or coal	Gas Liquid (at super cool temps.)
Solar Energy	N/A, field	N/A, field	1 - 5 million every hour	Field
Grain	7,000 dry	200,000	3 - 40 million every year	Solid
Wild Game	7,000	350,000	up to 300,000 every year	Solid
Wild Berries/ Nuts	up to 7,000	10,000 - 400,000	up to 3 million every year	Solid

RANGE OF ENERGY GRADE CHARACTERISTICS

	High (most Valuable)	Mid-high	Mid-low	Low (Least Valuable)
Weight Grade (Btu's per pound)	15 Thousand	10 Thousand	5 Thousand	1 Thousand
(GJ per Kilogram)	7 Million	5 Million	2.5 Million	500 Thousand
Volume Grade (BTU's per cubic foot)	1 Million	600 Thousand	300 Thousand	100 Thousand
(GJ per cubic meter)	35 Billion	20 Billion	10 Billion	3 Billion
State Grade	Liquid	Gaseous	Solid	Field
Area Grade (ground surface area, Btu's/Acre)	1 Trillion	100 Billion	1 Billion	100 Million
(GJ/Hectare)	400 Trillion	40 Trillion	400 Billion	40 Billion

Pricing Factors List:

Oil: \$40/Bbl. = \$7/MMBTU
Natural Gas: \$1/MCF = \$1/MMBTU
Coal: \$40/ton = \$1.6/MMBTU
Electricity: \$0.05/Kw-hr = \$14.5/MMBTU

THE ENTROPY SUBSIDY:

The idea of peak demand, as stated, is that the entire world will be able to use renewable energy sources and therefore reduce the need for fossil fuels, including oil, causing the demand for oil to peak and decline. However the problem with using renewables exclusively is that they are not able to support their own production, such as supporting the energy needs of some modern day heavy industry inputs that are required for renewables production. For example, if you want to use a wood stove to obtain heat, how do you get the wood. In today's modern economy, you drive to the forest, use a chain saw to cut down and slice up trees, use a wood splitter to split the logs and then stack all the wood in a large pick-up truck to take back to the city. You may even use a backhoe to organize the wood off of the pickup truck. Now, imagine how all that works without liquid petroleum fuels. You walk to the forest, spend all day, or many days, chopping down the trees and cutting logs, use horses to pull the wood to your house, and finally you slowly cut and split by hand all the wood. The number of hours you need increases by magnitudes, such is the power of petroleum's entropy subsidy to the process.

Therefore, it is oil and other fossil fuels that must be used to some degree to support the technologies of the renewable energy source based systems. This is where the Entropy Subsidy Problem, as explained in Reynolds (1998 and 1999b), comes into play where low cost oil is used to create low cost renewable energy systems. Indeed, as the price of oil increases, say due to a carbon tax or due to scarcity, then the costs of setting up and obtaining any renewable energy systems will go up even faster. That is cheap oil subsidizes renewable energy systems and expensive oil reduces that subsidy. See also Hall et al. (1986) and Georgescu-Roegen (1975 and 1972). This phenomenon of the entropy subsidy can be understood by looking at some specific supporting industries.

The way in which a so-called "sustainable" economy works still involves mining. Wind and solar power, rechargeable batteries and all the ancillary equipment needed for an electricity based economy, such as power lines, require lots of metals, minerals and trace elements that take a tremendous amount of energy to mine, process and ship. But whenever energy is needed for such functions, more often than not it is a liquid fuel energy based on oil that is used, not electricity based energy. So when the economy needs to use less oil, all the methods of providing a renewable energy system inputs will themselves require electric systems to operate that are less effective, and therefore costs will go up as well and probably go up faster than the reduced use of oil. Indeed, to even consider mining machinery, processing machinery or cargo trucks using electric batteries to sustain such an economy would mean creating enormous costs.

What is likely to happen in the face of an oil price shock then, is that on the one hand, technology can continue to make the batteries cheaper to build, last longer and recharge more quickly, but on the other hand as the price of oil increases, the costs of mining the materials needed, processing them and shipping them to market will make the batteries more expensive. This means the problem with peak-demand for oil scenarios is that renewable technology depends heavily on being able to use equipment built with lithium, rare earth minerals and even copper such that as the use of oil goes down, the price of obtaining these industrial ingredients, and indirectly the price of acquisitioning of the capital and labour needed for the use of attaining these ingredients, will go up. This subtle use of energy behind the scenes to make renewables useful, means that petroleum price increases will cause renewable energy costs to increase, which is a loss of the entropy subsidy that petroleum creates now for all renewable energy costs.

Mining and minerals production, though, are not the only oil-dependent basic industry that will affect economic costs of renewables, farming and construction will too. For example, energy intensive farming with high cost oil means the price of oil has to affect all the food related costs. Also construction using dirt and soil movers, cranes and cargo trucks means that all new housing, new business buildings and crucially new large scale renewable solar and wind turbine infrastructure will increase in cost. This will make existing buildings worth more as well, but in turn increase rents for workers. Also the maintenance costs of capital will increase with oil prices. What these kinds of direct and indirect costs imply is that workers will have to pay more for their sustenance. But then oddly, if workers are forced to pay more for these things, including paying more for their energy and renewable energy as well, then they will require higher wages to pay for them, and that in turn means wages will have to increase with the price of oil making labour costs higher as oil costs more. This is an inflation cost spiral nightmare that will present itself forcefully as many a declining civilization has experienced in the past.

Then, higher labour costs will permeate all through any renewable energy systems making them also more costly than any current estimate of costs. Not only will renewable energy systems become more costly but these high cost secondary inputs, like mineral production and labour, are likely during a COVID-19 reorientation of the economy to incur bottlenecks and further cause disruptions to these systems so that they will not be available very quickly after the COVID crisis resolves itself. It is even possible for a number of energy and other companies to be forced into bankruptcy causing the organizational makeup for efficient labour use to have to be restructured, which will take time. Even oil alternatives like coal-to-liquids and tar-sands will experience such ratcheting up of costs as they encounter an entropy subsidy loss and COVID-19 restructuring as well, although maybe less so than renewables. So the idea that oil prices will provide a kick start to a more renewable life style is both true and false. True in that some oil alternatives will be used and lifestyles will be changed to reduce the use of oil, but false in that the world cannot easily and quickly replace oil with an all renewables or an all alternative non-renewables slate of energy resources.

Now, if we go through the same line of reasoning one more time, but we substitute an all renewables economy for high cost petroleum, we can re-analyse the result. Going back through the arguments, farming, mining and construction must all use electric based technologies implying a much higher costs of conducting those industries. Then labour will need higher wages to pay for its food, products and housing, and then firms must charge higher prices to pay for their labour, than the renewable systems themselves will cost more and so on. This is completely opposite to the industrial revolution where coal reduced input costs and allowed economies of scale in steel making. It is opposite to the 2nd industrial revolution where oil allowed ICE vehicles with better power to weight ratios of the engines and lower weight for stored fuel to re-invigorate transportation. A change in the opposite direction cannot possibly cause an invigoration of the economic process, as those previous energy revolutions caused, but quite the opposite. Nevertheless, global warming concerns, though real, may not be able to be reduced adding to the overarching civilizational problems.

This in no way means that it is important to artificially keep oil prices low. After all, we need to keep oil conserved during any energy transition so that it will be available as a long as possible to help. So restricting outputs to raise oil prices in general is good for society and the world’s economy for the long run. If in the 1950’s it was true that, “what is good for General Motors is good for the country,” then, today what is good for OPEC is good for the world. That is OPEC makes more money by conserving a precious natural resource for the future and makes it last longer for the entire world’s benefit. If they raise oil prices, then that induces economies to more forcefully find ways to use less oil.

COVID-19 AND MACROECONOMIC OIL DEMAND SIDE ISSUES:

The current price expectation for oil, as of this writing and which changes by the month, is that due to the new Corona-Virus (COVID-19) and with many potential worldwide shale-oil sources of oil, oil prices will stay low. The COVID-19 Virus has shown that it is possible to have a breakdown of the economy such that the demand for oil has and will decline precipitously. So far, the demand for petroleum drop-off looks to force oil prices into the teens per barrel (in real 1st quarter 2020 dollars) in order to force the complete shut down and cut off of all kinds of petroleum production regions particularly U.S. shale-oil production regions which may be hard hit at least for a while. In the long run, society may even learn better how to telecommute and use a lot less oil and thus such an emergency demand change could be permanent.

Still, the COVID-19 Crisis could end in a cure, although if the pandemic lasts too long, the young and the restless will be forced to work and will protest vociferously if they can’t work until they force the economy back to some sort of normalcy although at the cost of the virus spreading to everyone and an increase in the number of deaths. Either way, the demand for oil, although quite a bit lower now, will probably go up to normal levels, although an alternative line of reasoning says that they won’t go back to normal levels. The later idea depends on tele-commuting, on-line shopping and artificial intelligence aided work in conjunction with a world getting more used to conducting business on-line and by distance during the COVID-19 lock downs to cause reductions in the need for oil to low levels. Then even when some normalcy does return to the world’s economy, the need for oil will be some 15% to 30% reduced for years to come, not due to electric cars, but simply due to tele-commuting and other efficiencies and so keep the price of oil quite low. For example, a lot of schools and universities are getting more used to teaching on-line and this change may stay permanent.

In this scenario a sustained reduction in petroleum demand with some surges and retreats over a 3 month to 3 year period will make for a highly volatile demand side era. Oil prices would go up and down from say $10 to $50 due to sudden gluts or demand retrenchments. Then with tele-commuting, distance delivery of school work and daily social distancing as the new normal, oil demand will stay subdued for decades leading to a sustained $50 price for years to come. Still, once the economy does go back to normal, there will still probably be a lot of oil usage for deliveries, greater after work driving to obtain services and a greater use of oil in developing countries. So the death of oil will probably be greatly exaggerated. Jet aircraft journeys will still be efficient for long distance travel. In person meetings will allow better side communication for business and personal needs. K through 12 schooling will want kids in class to make sure they are studying, keeping active and getting physical fitness and artistic directions. Teens will go to parties. In developing countries motorized transport will only grow more necessary as development occurs. Plus breakdowns or hacks of on-line networks will create a need for car travel.

Indeed, one aspect of the COVID-19 macroeconomic effect is the idea that business transactions, business meetings, and other tele-commuting can all be done over the internet with a vast reduction in the use of oil based transportation. However, one possibility with that is if electric utilities, cable companies or wireless phone connections somehow breakdown either due to hacking or even local, in-country political attacks. If these systems break down in some way, then the need for commuting and business travel would increase even more substantially than what a wireless society scenario would predict. The COVID-19 pandemic might cause reductions in utility systems reliability due to labour supply disruptions even as a post COVID-19 economic boom tries to depend on those utility systems more, resulting in connectivity interference and a need for in-person business. Therefore, another scenario could see that society over-reacts to the COVID-19 induced recession and sees both a reverse change in attitude to social distancing and a surge in economic activity simultaneously. In this scenario people restart their normal activities with either a viral cure or even some deaths due to the virus. But the reaction to the new freedom is a huge burst of economic activity, transportation and oil use that sends the demand for oil to well over the 2019 oil requirement of roughly 100 million barrels of oil a day.

The real problem with the COVID-19 recession is that huge amounts of government loans, payments to workers and bail-outs will create a quantitative easing of epic proportion. The U.S. Federal Reserve and other central banks will be forced to make cash available to banks, businesses and loan holders. The U.S. federal government and other governments will be forced to make loans available to businesses to borrow to pay for unemployment benefits and to subsidize many key industries to keep them viable. Then once any hint of economic normalcy returns, and when oil prices start to rise, there will be so much electronic and physical cash sloshing about that, once the velocity of money takes off, there will be no stopping the inflation effects. Workers will be forced to demand higher wages and firms forced to raise prices and governments forced to print money to pay for all remain obligations. There will be hyper-inflation. It will probably look like the Weimar Republic inflation.

Interestingly, a close study of the fall of the Soviet Union, such as Orlove (2008), shows that utilities such as electric utilities, water utilities and cable systems can also break down as the general economy goes into chaos. That means there will still be a need for oil to deliver goods and services and to create those goods and services and even that petrol supplied generators will be needed in the face of utility break downs and maintenance problems. So temporary reductions in the need for oil may be just that temporary and the needs for energy, even at a lower economic level, could still be quite robust.

So if a post COVID-19 macroeconomic boom occurs and is more forceful than currently conceived, then the ability to switch out of using petroleum and into using renewables or other petroleum substitutes may be limited. Indeed, while the COVID-19 recession ensues, it could not only harm the ability of U.S. shale-oil and conventional petroleum production to get back up and running after the recession, but it could harm the ability of renewable energy systems to get back up and running after the recession too and even harm the ability to expand those renewable systems for years to come as well as the ability to expand the use of those oil substitutions. Such problems are especially daunting when considering aspects of the energy utilization chain (EUC), Energy grades and the entropy subsidy loss as oil becomes more expensive. If the world's societies' ability to use less oil and its ability to substitute away from oil is limited, then the short run price elasticity of demand will be quite low, say -0.01 and the post-COVID-19 macroeconomic boom could create an oil price shock of epic proportion.

OPEC AND NEW INSTITUTIONAL ECONOMICS:

Understanding OPEC is difficult. It cannot be considered to be neither a cartel nor any kind of market power, misallocating entity, as Asker et al. (2019) suggests, since OPEC does not inhibit any other countries' ability to find their own oil or to develop their own alternative energy technologies. Plus OPEC members are responsible not only to conserve a precious resource for future generations, but they are required to maximize their current citizens' social well-being and to save for the future. One way an oil producer can save for the future is indeed to constrain their production now. To call what OPEC does as a misallocation is to say that any retirement fund is a misallocation of resources. Furthermore, when the OECD invokes a carbon tax, they are in essence using monopsony power to try to extract value away from OPEC members towards their own welfare, which can also be construed as a misallocation of resources. Indeed, the OECD should applaud OPEC efforts to constrain oil production and raise oil prices as this is exactly what many OECD citizens want with a carbon tax.

However, OPEC is even more complex then at first meets the eye. For example you can use extraction costs or proven reserves data for OPEC members, such as those collected by Rystad Energy, and try to use those data to determine supply. However, such data for any given oil producer does not explain oil supplies since it does not get to the heart of the oil supply problem which is how much it costs to add additional supplies, i.e. how much it costs to discover new supplies. While a country like Saudi Arabia may indeed conserve its crude oil for the sake of future generations, and even for the benefit of current generations which acts like a savings account and not a misallocation of resources, nevertheless, most oil producers are at their maximum supply level based on their expected costs of expanding production and their need to warehouse oil to allocate resources for future revenues. The cost of expansion is determined based on their subjective probability of discovery, their institutions and their rational expectations of the future. None of their subjective probability data is either quantifiable or recordable making it impossible to estimate properly each of their supply potentials. This goes to the heart of the concept of the information and depletion effect of section 3 above.

Furthermore, in new institutional economics there are several theories, as Banerjee (2002) explains, about how an economy and its institutions interact with each other and this interaction will also have an effect on the oil market. The classical institutional theory, such as espoused in Acemoglu and Johnson (2004) is that institutional arrangements affects how an economy runs. An alternative theory given in Glaeser and Shleifer (2004) is that the way the economy runs affects its institutions. Banerjee (2002) even suggests that cultures and economies can try out different institutional arrangements in order to find the one that best fits their situation rather like cultures and economies picking and choosing technologies in order to find the best fit.

However, when it comes to OPEC what Reynolds and Kolodziej (2009 and 2007) suggest is that as oil prices themselves change institutions for oil producing countries change as well. Indeed there are two interesting strategies (what might be called institutional make ups) that every oil producer can undertake. One is a discount strategy where by International Oil Companies (IOC's) in an oil producing region are offered very low government take contracts which then incentives higher exploration and production. The other is a luxury strategy whereby IOCs in an oil producing region are offered very high government take contracts which then reduce incentives for high exploration and production effort. The incentive contract can actually change over time. The question is what would cause such a change in these contracts, i.e. a change in the institutions of an oil producing country. What Reynolds and Kolodziej show is that it is the change in price that changes these institutions. In other words, the economy, i.e. high or low oil prices for an oil exporter, change institutions more like Glaeser and Shleifer (2004).

However, the institutional make up of an oil producer is not just based on individual IOC contracts, it also affects OPEC as a whole and its strategy. What Loderer (1985) shows is that OPEC agreements made not much difference to oil markets when oil prices were high and rising in the 1970s but that OPEC agreements did make a difference when oil prices were declining and yet due to OPEC infighting and cheating, the end result was a somewhat limited ability on the part of OPEC members to come to an agreement and stick to it. This suggests that there is an element of game theory of oligopolistic competition regarding OPEC, which suggests a lack of cohesion by OPEC is not only possible but likely. However, there are two major oil producers that do have the ability of and by themselves to affect the world oil market and who would not need cooperative game theory interactions to be able to do it: Saudi Arabia and Russia. Note, due to the U.S. being more of an oil importer rather than an oil exporter, the U.S. economy and its relationship to the oil industry is counter-cyclical in nature, whereas most OPEC members' economies are pro-cyclically related to oil prices. So, the U.S. incentive is to de-regulate oil whereas most OPEC members want a lot of government control over oil.

RUSSIA:

On the surface, Russia would like to interact fully with OPEC but it may have some challenges. First, Russia would like to find more oil and even shale-oil resources which could be a challenge given the shale-resource supply theory above and the fact that Russia doesn't need any more natural gas supplies. Nevertheless, having a number of independent companies can help Russia in this endeavour rather than nationalizing the whole industry. Plus, Russian oil pipelines, natural gas industry and oil industry each have different strategies that will make it hard to consolidate itself into one national oil and gas company or even three companies. And if a national oil restriction plan were put in place, there might be cheating within Russia's various oil entities. Also Russia may not want to nationalize everything inside its boarders due to legal considerations for loan, stock holder and accounting issues in regard to international finance.

That being said, Russia could find a strategy to either nationalize or consolidate its internal oil industry and effectively reduce output in prolific fields that can more easily be contracted and keep on producing from low productive fields that require their operational costs to be supported while they efficiently drain themselves. Possibly during this COVID-19 crisis it may be possible for Russia to use emergency powers to either nationalize or buy-off internal oil companies or in some way adjudicate a nuanced rule of law to take control of them. Once that happens even though there will be less incentives for new exploration and development, nevertheless Russia would be much more empowered to negotiate with OPEC which may create a net positive effect.

A bigger question is: does Russia's overall economy benefit more from low oil prices or high oil prices? While relatively high oil prices are a net benefit to its economy wide productivity, nevertheless very high oil prices might cause some problems. The real struggle, then for Russia is how will its non-oil related economy fare? For example, seeing as Russia has an extensive farming economy, where high oil prices could be detrimental to each farmer's production costs, then even though Russia as a whole, with its extensive energy industry, will benefit from high oil prices, nevertheless a large swath of the Russian farming or other industries may not want too high of oil prices.

Still, Russia possess vast quantities of natural gas which can somewhat substitute for oil, and typically agricultural industries gain slightly when oil prices rise because food prices also rise and tend to rise faster than oil related costs to the farmers. Therefore, while some industries in Russia may suffer from very high oil prices, still Russia does possess the means to work around it. Russia does have extensive transportation infrastructure to be able to depend on coal and nuclear produced electric power and its cities are dense enough to be able to survive with lower quantities of oil. Its metro area Dacha systems are still pretty much intact, although not quite as vibrant as they once were, so that each city can still produce fresh produce for itself. Also with China's Belt and Road initiative, new and better infrastructure such as bullet trains to China may be put in place and help with cargo options and tourist travel so that non-oil related industries can remain viable. So even though Russia does have vast land areas that often need gasoline, diesel fuel and jet fuel to adequately reach towns, mines and remote factories, nevertheless, and luckily, most of Russia has good infrastructure and dense cities that can survive in a high oil price environment.

All of this suggests that Russia's economy would have a net gain from an OPEC+ oil production quota reduction agreement than not. Indeed, Russia could easily act unilaterally and not depend on OPEC at all, as in the marginal duopoly suggested below. So, in overall economic terms, Russia would gain with higher oil prices particularly due to its extensive mass-transit infrastructure.

THE SAUDI, RUSSIAN AND OPEC ++ INTERACTIVE RELATIONSHIP:

As of this writing not only is there the organization of petroleum exporting countries (OPEC), which ideally tries to stabilize oil prices, there is also OPEC+, and OPEC++ as well. OPEC+ includes OPEC, Russia and some other non-OPEC oil exporters and OPEC++ would include any other major petroleum producers, whether they export oil or not, in particular including the United States and the states within the U.S. It used to be that it was mostly Saudi Arabia inside of OPEC that induced most of the changes in the oil market worldwide as Reynolds (2011b) suggests. Ideally, then, OPEC or OPEC+ or OPEC++ would reduce total petroleum production during demand declines and increase total production during demand surges in order to stabilize the price of oil, although such coordinations are often difficult to carry out. Indeed, what the 1980s and early 1990s show is that an OPEC cartel game of Saudi increases and decreases of production to force prices lower and then higher in a game of non-Saudi OPEC punishment and reward does not work well. Once members in one month agree to OPEC cuts in production, they immediately start cheating within a few months of the agreement such that prices go from low to high to low again in a never ending game theoretic play of cheating and punishment. That same game of chicken would occur in any OPEC+ agreement and especially in any OPEC++ agreement. After all, inside the United State are hundreds of independent oil companies that don't know how to coordinate their own regional production outputs, so that even if they did agree to cutbacks or were forced to reduce their respective outputs, or even agree not to explore for or develop new prospects, there would be cheating on those agreements.

The more likely situation is that OPEC, OPEC+ and OEPC++ will attempt a first round of agreements, but then a number of oil producing fields around the world will cheat. Whereupon Saudi Arabia and others will have no choice but to create a surge in supplies, and with such a low COVID-19 recession induced demand trough, push prices down to the teens and force shut downs and consolidations. In the U.S. for example, all kinds of companies could go bankrupt, be bought out and be forced to drain remaining resources but then not be allowed to drill any new wells. Assets and mineral rights may be put under control of large remaining companies who will attain very long term mineral right agreements for the remaining oil fields where by the U.S. oil production crashes but is consolidated. Thus, potential capacity itself will decline in the U.S., or at least be put under the control of large companies, and those companies will be able to reduce and expand production more imperiously to maximize value, but with an eye toward circumventing agreed on cutbacks when it suits. Clearly, then, OPEC or OPEC+ or OPEC++ agreements are never going to work out over a long term, with cheating and counter supply expansions causing a price rollercoaster, although they may provide short run increases (and decreases) in prices. Rather the real issue over the longer term is Saudi Arabia and Russia of and by themselves. The U.S. itself is also not a factor in the oil market over the longer term due to its strong internal anti-trust laws and its relatively diversified suite of petroleum companies that will never be able to agree with each other.

The issues is not so much the medium term of a OPEC++ world of cheating and agreements, but rather after the post COVID-19 economy resumes. Then Saudi Arabia and Russia will each have about 10% of world capacity, and could each act like a duopoly at the oil market margin. While one theory suggests that there is the potential for a Saudi-Russian marginal cartel that requires each participant to coordinate with the other, it may be something else entirely. The real concern for the world is when both Russia and Saudi Arabia act unilaterally irrespective of each other's game theoretic position. If each unilaterally choses to reduce its output by say 50%, and assuming the short run oil demand elasticity during an oil shock is on the order of -0.01, then they could each independently raise oil prices by five times. That is a 50% reduction in each of their outputs will more than double each of their revenues. But they could quadruple their revenues when working in tandem and raise oil prices by more than a magnitude. Instead of $30 per barrel oil, we could see $300 to $1000 per barrel oil for a short run inelastic demand.

While during the COVID-19 induced recession, with demand destruction so low and oil prices so low, it is impossible to imagine that Saudi Arabia and Russia could each unilaterally control the oil market. But if the U.S. shale-oil Hubbert trend maximum available production is lower, due to consolidations and institutional changes on mineral right ownership durations, and if U.S. petroleum mineral rights in general are consolidated, making U.S. production capacity all the more constrained, and if other world producers have had to take away production infrastructure, then indeed the supply potential of the world could be vastly reduced, leaving Russia and Saudi Arabia with the room to control the market much more forcefully.

One concern for Saudi Arabia is that a bellicose United States could invoke a no OPEC (NOPEC) law that could allow the U.S. to use its banking, financial and monetary power to punish Saudi Araba and other OPEC members for any such action. One strategy from a Saudi Arabian legal retaliation against the U.S. perspective is given in Reynolds (2020), whereby Saudi Arabia can use the U.S. court system to Saudi Arabia's own advantage to stop a U.S. retaliation against Saudi Arabia. And through the U.S. the OECD would fall into line.

Another concern is Russia itself. Given that OPEC will inevitably have a hard time agreeing to cuts and sticking with them, then Russia is a key to world oil prices. The question is, would Russia endeavour to make oil production cuts on its own since it has a number of independent oil producing entities running inside of Russia. Each of these entities may be loath to reduce each of their shares of oil production for the good of Russia as a whole, in which case the central government may have a hard time strong-arming these entities. At this point, though, with Vladimir Putin being able to change the constitution, it should be possible for the Russian central government as stated to deftly find a way to coordinate the Russian oil producers to constrain their production capacities.

ONE FORECAST:

With COVID-19 causing a catastrophic decline in oil demand and a toping up of all storage facilities, oil prices will crash. And even if they lift up again due to OPEC++ cuts, they will probably crash again in a cyclical replay of the late 1980s and 1990s of agreement making and cheating. Then it probably won't be long before a number of oil producing companies, oil wells and petroleum developments worldwide will grind to a halt. While some oil producing fields will be relatively easy to bring about extraction rate slowdowns, some oil fields will see reserve destruction due to the curtailments and will then have lower ultimately recoverable reserves because of it. Although new enhanced oil recovery (EOR) techniques may be able to go into old fields and reinvigorate them so that there is only minimal reserves destruction, but only after a time.

Nevertheless, once any sign of economic normalcy resumes and old and new oil wells get back up and running, there will probably be a delay in being able to get back up to the production levels of the pre-COVID-19 days even as the normal Hubbert Curve trends continue to reduce the limit of world conventional petroleum and U.S. shale-oil production potential. Then with natural decline rates of extraction for wells, with some reserves destruction and the slow development of EOR on a number of idled wells, and with the world's Hubbert related petroleum production potential causing a lack of new discoveries, oil output will be substantially lower. Even oil or renewable alternatives will be constrained or take years to put in place. The end result as economic demand reinvigorates upward and as lower potential production pushes back, is that oil prices will rapidly rise. Then OPEC institutions will rapidly change causing most OPEC members to further constrain supplies. Then Russia and Saudi Arabia will be put into position of each being a marginal duopolist with the ability to constrain supplies even more in order to receive a net gain in oil export revenues.

Within all these events lie three main issues. One is how much decline in demand will the COVID_19 induced recession cause? Second, how fast can a post COVID_19 economic boom induce oil demand increases go back up again? Third, how quickly can the inventory of 2019 oil wells and oil fields get back up and running? With this in mind, we can use Schwartz's (1991) long view scenario building to see how the future will play out.

One idea is that COVID-19 will not cause a long delay in economic activity with a resurgence in the economy within months, although at a new "on-line economy" based lower level oil demand and also with the bailout to put oil-wells back into production quickly. Other oil producers around the world will also obtain help to put in place a number of shale-oil fields, so that world oil production can adjust back up again even with OPEC cuts. Therefore the world's economy will see a slow somewhat painful but palatable transition to a post-Hubbert world and not much post Covid-19 economic pain. Oil prices will start rising within months but not volatilely and in an orderly fashion.

The second idea is that COVID-19 will last a year or more with a huge oil demand destruction. Then the economy will finally get back on its feet after a few fits and starts but take some time in doing so. Interestingly, though, the world's economies will have learned to use less oil due to consumers being more used to being on-line, and thus there will be a large reduction in oil use. The slow return of the economy after such a long delay will help the world's oil suppliers to each resurrect back up more slowly and again a transition to a post-Hubbert, post COVID-19 world will be palatable.

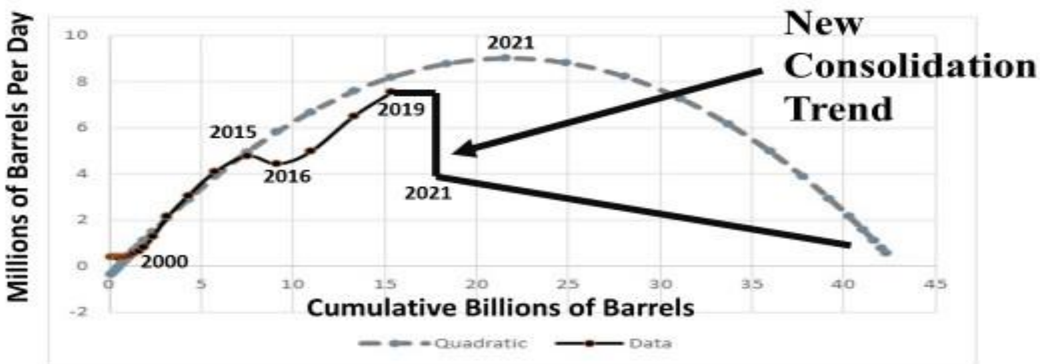
A third idea, although certainly along the lines of Schwartz (1991) one can come up with probably ten or more such scenarios, is the following. A huge COVID-19 recession will see spectacular oil demand destruction and a number of petroleum suppliers in the U.S. and elsewhere going out of business and causing the shutting down of wells fields and exploration entirely for a time. Then after about 8 months, either due to the young and the restless pushing for normalcy or due to a cure, or even due to everyone working in COVID-19 protective gear like painter overalls and masks that are changed out every day, the COVID-19 recession turns into a rather large economic boom. Government low interest loans, quantitative easing and tax cuts will have created a spree of spending, driving and flying unmatched in history. The economy booms so fast that oil production can barely ratchet up. Indeed, during the financial crisis, oil demand hardly changed at all, so a post-COVID economy may react the same and still use plenty of oil..

Also, if utilities break down, that will further exasperate any economic upturn but it may also mean that people will need more petroleum energy. Also since a lot of renewable energy is located in isolated locations, then a shut off of the utility connection to those energy sources can cause problems. With oil, coal and to some degree natural gas, there is an availability to store the energy and to transport it by different means such that a single cut off of supplies is able to be overcome.

Not only that but oil producers around the world will have had to let their oil workers go into COVID-19 shelters as many of the wells will have shut down. Those workers, then, will have changed jobs and will not be able to be readily found, so there is a shortage of workers at all of the oil fields around the world making it all the harder to put fields back into production. In addition, the world's petroleum producers will have changed most of their institutions such that each country will have centralized their control of oil. OPEC members will each unilaterally have changed contracts with the international oil companies (IOCs) to give their own governments more control over petroleum production and a higher percentage take in net revenues. Non-OPEC producers such as Russia will also have been able to use the COVID-19 emergency to legally put all of their petroleum production industry under complete government control. Even the United States will have been forced to change. U.S. private mineral rights holders will be forced to have lease contracts consolidated where oil companies gain control of the mineral rights for years, and even decades, so they can warehouse the mineral rights as needed to better plan pipeline expansions or field integrations. Large producers will own and control large swaths of U.S. mineral rights in order to carry out this coordination of exploration programs and developments such that supplies will increase much more slowly and more carefully than expected. Indeed, oil companies after the COVID-19 recession will be extra carefully not to expand fast as they will have had a slew of loss making wells that they need to pay for, even as the U.S. shale-oil and conventional Hubbert Curve limits create a *defacto* lower boundary of potential U.S. oil production. The U.S. regulatory authorities will be less forceful in reducing consolidations in order to help oil companies clear away old debts and keep energy supplies available but with many fewer companies left in play.

What this means is that institutional and physical changes to the world's petroleum industry will create a supply limit lower than the Hubbert Curve limit of Figure 12 for the world and Figures 15 and 20 for the U.S. shale-oil production rate, as shown in Figure 22, and where a number of unconventional oil projects will be very slow to restart or get up and running post COVID-19. With a lack of oil and oil demand booming, oil prices would rise fast. Then workers would quickly complain and demand higher wages and firms costs would rise and the firms would have to quickly start raising prices. Indeed, due to a number of firms having shut down their operations during the COVID-19 recession and needing time, money and new workers to ramp back up again, then workers will gain leverage for higher wages and firms will be forced to raise prices.

Figure 22 The Hubbert Quadratic Consolidation Trend
Petroleum Production (Q) versus Cumulative Production (CQ)



Moreover, because of all the world's government induced low interest loans, quantitative easing and public spending programs put in place during the COVID-19 recession, there will be a lot of cash sloshing through the worlds monetary systems. As spending steps up, the velocity of money will sky rocket putting a lot of pressure on prices and wages. Then a hyperinflation spiral will ensue forcing governments to print money just to be able to function at all. But even as the hyperinflation ensues, the economy in general will not rise to quite the height it reached in 2019 and indeed a second long economic decline will ensue after the COVID-19 recession. This second recession will be a stagflationary event, with both economic decline and high inflation, and although the COVID-19 recession will have helped in preparing people for a second recession and stagflation, nevertheless it will be sever. The end result after accounting for inflation will be oil prices in the \$300 to \$1000 per barrel rang in real 1st quarter 2020 dollars and all the higher in inflationary dollars.

IV. Conclusions

A lot of the engineering aspects of energy system, and therefore the energy economics of those systems, deals with the barriers between a source of energy and the final use, or service, of that energy. The physical barrier which must be broken down to get from the source to the service along the energy utilization chain (EUC) determines the cost of energy and the final service determines the value provided by any specific type of energy. The barriers between the source and the service includes not only barriers of distance, but they can include the physical characteristics of energy types and the timing of when energy is needed compared to when a source is available. Indeed, often when energy prices are compared what is missed is the fact that some types of energy, like renewables, require a complete change in lifestyles in order to use them, such as only using an appliance when solar energy is available. Such subtle life style change requirements are often not reflected in energy price data. Indeed, in my own experience no one can truly understand energy unless they live in Alaska. Thus, in order to understand energy in general, one needs to understand all of civilization.

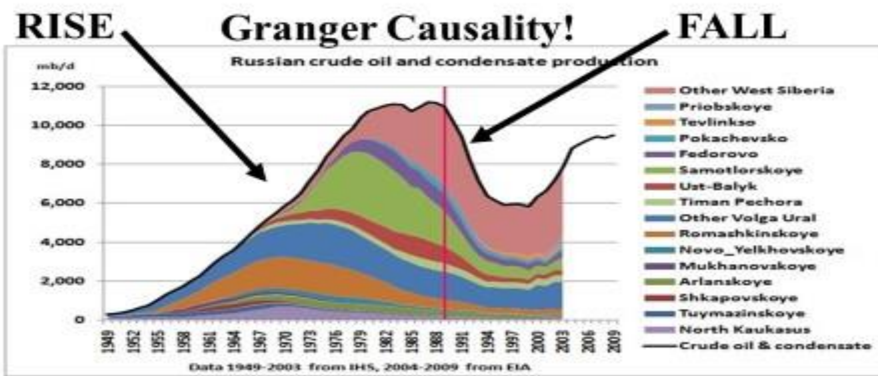
7. CIVILIZATION

Civilizations have risen and fallen throughout the millenniums. Typically the characteristics most important to a rise and a fall is the energy resource upon which the civilization is based whether it be an agricultural related energy source such as wheat or maize or a denser energy resource like oil. Examples of such civilizations can be the ancient Mayans, the ancient Mycenaean's or the ancient Romans' each with a vast empire and technologies that were the envy of the world in their day, whereupon, often due to weather related changes, they went into decline. While most see such a history as a call to reduce global warming causing carbon emission, a more germane concern is oil itself. And there is in fact a perfect example of such a hugely important modern industrial civilization dependent on such a fossil fuel.

Consider the Soviet Union. It was civilization of immense geographic and economic power. It had culture, engineering wherewithal and governmental agency. The mundane thesis is that it somehow was so inefficient economically that it lasted for 70 years by merely terrorizing its citizens alone, but that the freeing up of its society to openness immediately caused a crash and all of its technology suddenly didn’t work. A more sophisticated argument is that the Soviet Union had a hodgepodge of both government run infrastructure, like railroads and power utilities, along with private markets, such as farmers’ markets and the dacha system, that was relatively effective at both defending the empire from Nazi aggression and delivering a good enough economy to give prosperity to most people, that is it was a mixed economic system, neither pure socialistic nor pure capitalistic.

The U.S. is also a mixed system that subsidized trans-continental railroads, jet technology and regulated oil and gas activity, but also used free markets to prosper. Yet the Soviet Union fell while the U.S. system, though damaged by the financial crisis, still remains relatively strong. Looking more closely at the energy supporting the Soviet Union, though, it is clear that its oil production was the key to its success. See Reynolds (2016 and 2000) for a full history. Indeed, Figure 23 shows the Russian oil production from 1949 until 2000 and which gives the visual effect of their rise and fall. Note that during the rise of the Soviet Union that oil production was going up, but right at the decline, it was going down. Indeed, from 1949 to 1970 Russian oil production averaged over 10% increase per year and even from 1980 to 1987 it increased at about a half per cent per year, whereupon it fell. By October of 1989 the rouble was devalued by a magnitude and the stagflationary economic collapse was on. Oil production fell by almost half during the declining years.

Figure 23 The Soviet Rise and Fall Vis-à-vis Oil Production



Many still credit U.S. President Ronald Reagan with both the end of stagflation and the end of the Cold War. However, in the 1980s the price of oil declined due to demand side changes, which Saudi Arabia and OPEC could not overcome to keep prices high, as Figure 12 shows and that started happening after the 1973 oil price shock. So the 1980s U.S. and western boom in the economy was mostly due to oil reduction technology and investments, like using nuclear energy, that started in the 1970s. The Cold War, though ended with a different oil production phenomena of an oil supply side decline within the mostly closed economy of Eastern Europe and Central Asia. The usual idea for the cause and effect is that the decline of the USSR caused the oil production decline, but Reynolds and Kolodziej (2008) show that granger causality to be the reverse: the oil production decline caused the GDP decline. Note that natural gas production in the late 1990s was increasing for the Soviet Union which means that it could not have been internal chaos causing the oil production decline since oil and gas use similar engineering. So, to give U.S. President Ronald Reagan credit for the Cold War win is like Nike athletic wear taking credit for a Wimbledon or Roland Garros tennis player winning a championship. Clearly, it was a scarcity of oil reserves, given the technology that existed within the Soviet Union, that caused the oil production to decline. Scarcity and growth can indeed mean that more scarcity determines a decline in GDP, and it’s been true in that way for many civilizations and it was true for the Soviet situation.

You can also argue that the Soviet inefficient system changed to a more technologically advanced market system which caused their oil production to have a renaissance and rise such that thus it was the inefficient system itself that caused their ruin. A similar argument works for the fall of Rome. If ancient Rome only had 21st century technology they would never have fallen. But the argument like such a Soviet argument is anachronistic. What this means for our current global economy "civilization," is that the world is likely to have a major decline in its economy as oil production goes down. This will entail the slow substitution of other energy sources for oil such as coal, nuclear and renewables, but more likely there will also be a need for massive infrastructure changes such as transportation infrastructure to overcome high oil prices.

Note, the true fall of the Roman Empire was not due to the invasion of the Barbarians but due to the Crisis of the 3rd Century that affected both the Ancient Roman Empire and even the surrounding barbarian peoples. During the crisis of the 3rd century as Fagan (2003) explains, Rome had a cooler wetter weather pattern that made it impossible to grow wheat and instead farmers had to grow millet as an alternative. The decline in productivity of planting and harvesting millet instead of wheat made farms less able to make money and trade. Another problem surrounding that period, and just before the Crisis of the Third Century, was the plague that caused the labour supply to diminish, but that may also have enhanced the Roman economy due to Schumpeter (1942) like creative destruction. The fall, though, happened due to weather changes.

One thing that the Roman example suggests is that the economic output per capita should not have declined quite as much with both population and total output going down at roughly the same time. But in fact the productivity of labour also declined. A more pertinent aspect of terminal Roman history is that multiple problems can layer on top of each other such as disease, weather pattern changes and finance. Thus it was during the Crisis of the 3rd Century that Roman inflation took hold where authorities took single denarii coins and hammered a 2 on them instead of a 1 to double each coins single value. This suggests that the 21st Century Global Economic Civilization could go through a similar bout of change with a corona-virus health care problem, an initial economic plunge, a bout of quantitative easing, and the coup-de-grace an oil price shock of epic proportion with accompanying stagflation, hyperinflation, unemployment, energy restraints and migrations all across the globe.

8. THE FINAL HUBBERT ASSESSMENT

The usual way that financiers, geologist and engineers, and even quite few economists, view petroleum supply is based on the costs of extraction. Therefore, if oil costs $10 per barrel to extract in a region and the price is say $50 per barrel, then that implies there is plenty of oil from that region available. If the cost is $45 at a $50 price in a region, then that implies maybe less oil is available from that region. However the cost of extraction while pertinent is not the most pertinent aspect of crude oil supplies, rather the overarching basis of supply is the discovery costs of oil not its extraction costs. But financiers, geologists, engineers and economists cannot explain to anyone what the cost of discovering oil is because it is almost unobservable on the market. Since financial markets and most people cannot accept anything that is "unobservable" then such information is discounted and so most people believe the oil market is only a cost of extraction market and nothing more. The real issue is the process of discovery which tends to make oil supplies quite inelastic with respect to price.

After all, the pertinent aspect of supply is the season and what you can plan, contract and physically get done within the season, and which creates a limit of what is possible. But once you have found and have developed an oil reservoir, the biggest share of the total cost of production are sunk costs, and just to maintain your production infrastructure you need to continue to pay to keep it in operation even with low priced oil sales. Otherwise, if you shut in the well and it degrades, and then when prices return to normal, you will not be able to restart production in order to repay all of the upfront costs already incurred. If you have discovered something and have not yet developed it, you can wait through low price eras and develop it later, but ounce something is developed, it is usually kept in production until drained. Some variation on extraction rates of existing reservoirs is possible to the degree it does not cause reserves destruction. What all this means is you cannot understand supply by quoting the cost of extraction, you have to understand supply by understanding the exploration process itself. Even if a potential reservoir costs $10 to extract a barrel, it does not mean that those barrels cost $10 to find and to expand the capacity therein. Discovery and production are completely separate cost issues.

Trends in oil production follow a Hubbert Curve pattern due to the information and depletion effect. Indeed it is due to the information and depletion effects that is the root cause of Barnett and Morse's (1963) misleading analyses, and to some degree with works like Pooley and Tupy (2018), as they don't look at the finding costs of underground natural resources, like oil, but only look at the extraction costs, and thus they do not understand the trends inherent in those search processes. While it may be hard to predict the trend specifically, the low, high, low sequence of discovery and production is based on theory and empirical evidence as Hubbert (1962), Reynolds (2009, 2002, and 1999) and Jacobsson et al. (2012) show. The trend in U.S. shale-oil does indeed look to follow such a trend. While it's possible to econometrically show that a straight line trend in shale-oil is occurring, that does not fit the theory of non-renewable natural resources as explained in this treatise, which is to say that to depend so heavily on econometrics as the profession often does, is a mistake as economic and engineering theory are vital in gaining a true energy analysis.

Also seeing as there was the unexpected shale-oil revolution and the unexpected COVID-19 demand side fall-off, then you cannot in reality use the Hotelling-rule to fit the practical example of a mineral economy model due to Pindyck's (2007) and Dixit and Pindyck's (1994) and Reynolds (2013) uncertainty theory effect. For example such analysis as Nystad (1988 and 1987) cannot be used. On the other hand, this same lack of possible foresight might suggest that you can't use a Hubbert curve either. Actually as long as oil prices stay reasonably stable, and relatively high, then the economic supply theory behind the Hubbert curve is sound. The oil price may change, but the Hubbert curve trend as a limit for production (or more accurately for discovery) of a defined resource in a defined region will hold. It may be that the demand for a resource is so low, that there is no need to follow the trend or no way to know where that limit is since you are well below that limit. But based on theory alone, the limit theoretically exists and can be handy in helping make plans for a future with less oil. Therefore the question is will the U.S. shale-oil follow a Quadratic Hubbert Curve or a larger Lambda Hubbert Curve. The evidence based on technological evolution, U.S. institutions and geological information is that the U.S. shale-oil resources are following a Hubbert quadratic Trend in production not a Lambda Trend. Therefore, it is highly likely that the U.S. shale-oil production will peak within a year or three, or, due to changes in U.S. institutions surrounding the COVID-19 recession and the aggregation of those resources, that the U.S. production will decline relatively quickly pushing market power into OPEC's hands and in particular into Saudi Arabia's and Russia's hands.

In addition, other potential shale-oil producing regions will not be able to rush in to fill the U.S. shale-oil gap due to the unique feature of shale-oil and shale gas being substitutes in production when shale gas is not needed but being compliments in production when there is a natural gas market and natural gas infrastructure in existence. Because most other potential shale-oil production regions either do not need natural gas or do not have natural gas infrastructure, then it will be much harder to develop those shale-oil resources as a result, unless the price of oil goes much higher.

As oil prices go up, many OPEC members will be compelled to look on their oil production as a luxury goods supply market, that is they will increase their government take of oil production and consequently reduce supplies. So instead of oil supplies rising with high prices, they will tend to be reduced so that OPEC members can have a larger take. However, two oil producers, Russia and Saudi Arabia may use their relative large market share to reduce output substantially and raise prices by quite a lot. Since the short run demand for oil can be highly inelastic, then if both Saudi Arabia and Russia reduce their outputs by roughly 50% each, then world prices might go up by a magnitude or more into the $300 to $1,000 per barrel price range. While the OECD may decide that this is using monopoly power to the OECD's disadvantage, it could in fact be to the OECD's benefit by saving a precious oil resource for future generations and pushing very difficult energy alternative strategies to be put in place faster. Nevertheless, Russia may gain economically from such a strategy, and Saudi Arabia can use Reynolds (2020) legal strategy to defend itself from any U.S. NOPEC law retaliation. Also the world should be prepared for a more constrained oil market where alternative energy and energy substitute infrastructure will have to be developed, and not just renewable energy but nuclear and coal resources as well.

In the final analysis in order to forecast a price of oil, you need to understand the marginal cost of exploration based on the information and depletion effects and based on the institutions running the exploration, and not just the simple cost of production. Then you need to understand the value of energy and in particular the barriers that different types of energies encounter to be able to provide energy services vis-à-vis the energy utilization chain and the entropy subsidy effects. None of the prominent text books on natural resource and petroleum economics explains these concepts and so this treatise has had to be extensive in order to give point by point detail of how energy works.

Generally, the global economy can be considered a civilization and like many civilizations before, it will have to adapt to constrained resources. This treatise, then, can be considered not only a concluding chapter to Reynolds' (2011) *Energy Civilization: The Zenith of Man*, which is a counter argument to Bronowski's (1974) *The Ascent of Man*, this work should also be considered side by side with such illuminating epics as Reynolds' (2016) *Cold War Energy: The Rise and Fall of the Soviet Union*, Stewart's (2000) *Anasazi America: 17 Centuries on the Road from Center Place*, Gibbons' (1776, 1781 and 1783) *The Decline and Fall of the Roman Empire*, and Wood's (1985) *In Search of the Trojan War*; all classic accounts of a particular civilization's terminating causes. As we embark on our own civilization's maturation, understanding previous civilizations' maturations can help in our own age's adaption. Typically in these civilizations we encounter certain traits that are similar such as high inflation, like Rome's coin changing, such as lots of migration, like the sea peoples migration of the terminal Mycenaean age, where Mycenae was initially an attacker of Troy but later on became a source of migrants that overran Troy, and such as the collapse of the banking system like the ancient Anasazi food banks that fell into collapse. All these traits can be found occurring during the collapse of the former Soviet Union.

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